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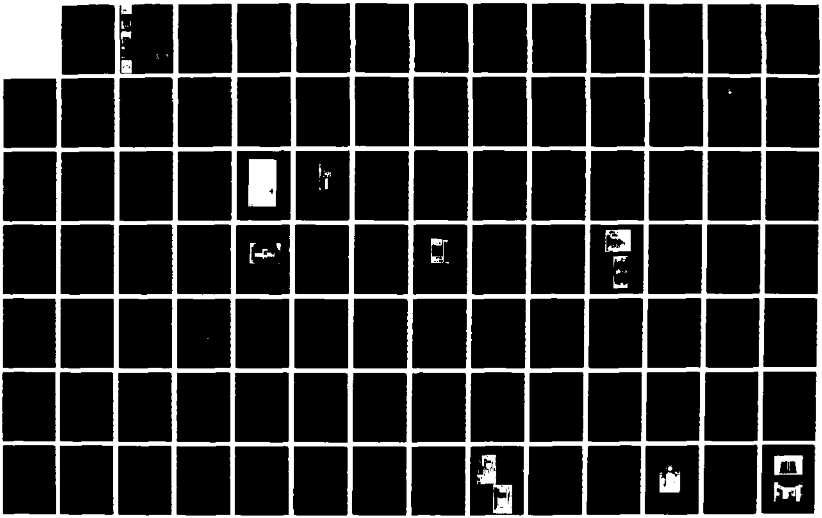

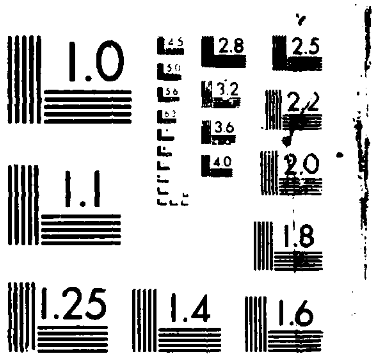

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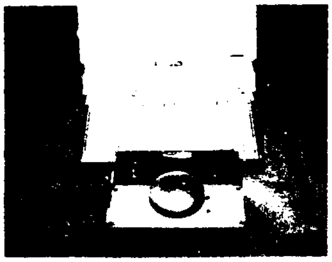

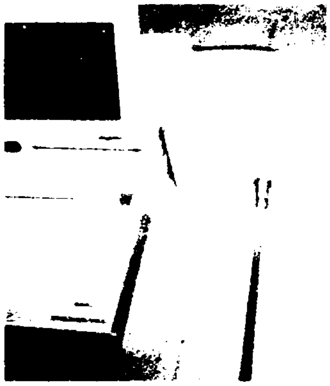

GEOTECHNICAL LABORATORY

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DEVELOPMENT AND INITIAL TESTING OF THE AUTOMATED MILITARY CONE PENETROMETER

by

William Edward Perkins, CPT, US Army

US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

March 1988

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for Georgia Institute of Technology
Atlanta, Georgia 30332

and US Army Engineer Waterways Experiment Station
PO Box 631, Vicksburg, Mississippi 39180-0631

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Since the late 1950's, the United States military forces and the US Army Engineer Waterways Experiment Station (WES) at Vicksburg, Miss., have successfully used an abstract value called the Cone Index (CI) as an indication of soil strength. The CI is the backbone in establishing the current empirical soil-vehicle relationship for predicting the ability of a soil to support sustained ground oriented military vehicle traffic. The military's conventional proving ring cone penetrometer is utilized to measure a soil's CI. Over the past 25 years, a large CI data base has been established utilizing this piece of equipment.

In addition, recent developments have been directed to analytical modeling of the soil-vehicle relationship. This modeling technique utilizes the fundamental engineering properties of a soil to establish this relationship. Because of the extensive data base of CI values, WES developed a mathematical model which led to the development of theoretical equations which correlate CI with the fundamental engineering properties of a soil.

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Specifically, these equations present a means by which CI can be predicted based on the engineering properties exhibited by a soil. These predicted values of CI can then be used to establish the soil-vehicle relationship.

The basis of the research presented in this report originated from a need to update the conventional proving ring cone penetrometer with current technology and therefore provide an efficient and effective means of validating the WES mathematical model. This particular report presents a general background study of military trafficability studies and the need for initial development and validation testing of an automated military cone penetrometer system. Specifically, this report covers only the first phase of an ongoing testing program to improve the military's ability to measure CI and to validate the WES mathematical equations used to predict CI.

DEDICATION

I would like to dedicate this research project and the time I have spent in Graduate School at Georgia Tech to my older sister, Beverly 'Perkins' Black. By no choice of her own, she is mentally retarded and does not have the ability to enjoy some of the fruits of life which so many of us take for granted. The cornerstone to my desires in life is constructed on her persevering and 'can do' attitude to complete the so-called "menial" tasks of daily life. To the teacher who has provided me with the greatest lesson in life, I thank you.

ACKNOWLEDGEMENTS

The completion of this project marks an especially thankful and gratifying point in my life. By itself, it represents the happy, sad, bewildered, and successful times of the past 18 months of my life which have been spent as a Graduate Student at the Georgia Institute of Technology. The completion of this research project could not have occurred without the encouragement, assistance, expertise, understanding and friendship of a number of persons.

By far the most influential part of my life for the past 18 months has been my wife, Gayle. Without her love, support, and understanding none of this could have been possible. Regardless of the situation, she was always there when I needed a close friend, and to her I say, "IT'S TIME TO SMELL THE ROSES!"

I would like to send a special thanks to my mother and father for the encouragement, love, and thoughts of wisdom they have provided over my entire life.

I would like to thank LTC Terry D. Hand, Assoc. Professor of Civil Engineering at the United States Military Academy, and the United States Army as a whole for having confidence in me and for providing me with the opportunity, time and funding to attend graduate school.

Next, I would like to thank my faculty advisor, Dr. Bachus. Throughout this research as well as the total 18 months, he was always available providing expert guidance with an understanding

ear. Without his encouraging support and mentorship the completion of this project and subsequently my graduation from GT would not have been possible.

I am also grateful to the comments and assistance of Dr. Lai who served as a part of the reading committee for this project.

A special thanks goes out to the personnel in the Mobility Systems Division of the Waterways Experiment Station at Vicksburg, Mississippi, who made this research possible. The energetic support of Newell Murphy made the original idea of an automated military cone penetrometer a reality. Additionally, without the computer programming expertise of Billy Palmertree and the mechanical wizardry of Bobby Reed, the successful completion of this project would not have been possible.

Also, a special thanks goes out to the whole faculty and staff of the Georgia Tech Geotechnical Department. Your professional guidance and assistance over the past 18 months have provided me with a better understanding of Geotechnical Engineering and life in general. Specifically, I would like to thank Dr. Barksdale, Dr. Williams and Professor Sowers for sharing their knowledge of civil engineering with me and providing me with the tools I will need in the years to come. In addition, I appreciate the secretaries, Vicki and Carol, always having time to answer general questions and being good friends. Of course, thanks Ken for finding the support materials that always seemed so difficult to find.

Finally, I would like to thank all of the other graduate

students at Georgia Tech for putting up with me during both the good and bad times of the past 18 months. Your friendship will always be cherished.

PREFACE

This report was prepared by CPT William Edward Perkins in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering to the Faculty of the School of Engineering at Georgia Institute of Technology. The study described herein was sponsored in part by the US Army Engineer Waterways Experiment Station (WES) Geotechnical Laboratory (GL), under the Army Mobility Work Project AT22-C-004 entitled "Wheels, Tracks, and Soil Dynamics Influence on Mobility". The WES is grateful for the association with the University and the opportunity to support such education and development of professional excellence. The author acknowledges the support given by Mr. Newell Murphy, Jr., Chief, Mobility Systems Division, GL and Dr. William F. Marcuson III, Chief, GL.

COL Dwayne G. Lee, CE, was the Commander and Director of WES during the preparation and publication of this report. Dr. Robert W. Whalin was Technical Director.

CONTENTS

PAGE

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

A key factor in the success of the United States Armed Forces on the modern battlefield is the military's ability to access information about the theater of operations in an effective and efficient manner. Technological advancements in the past 15 to 20 years have created a situation where a military unit that lacks the speed and efficiency of information flow will find itself at a disadvantage. This is especially true for the ground oriented military units. These units rely heavily upon the ability of their military vehicles to effectively traverse the terrain in the theater of operations. Whether the mission is to conduct troop and equipment movements or to conduct a resupply, the ability of these units to accurately and efficiently determine trafficability information in the area of operation could prove to be the difference between success and failure on the modern battlefield.

The information concerning a soil's ability to support military vehicle movements is accomplished through the conduct of trafficability studies which utilize a cone penetrometer device. Dating back to the late 1950's, this device has a long proven record in its ability to provide reliable data in the investigation of vehicle-soil relationships. However, its extreme labor intensive operation, as detailed in the Army's

Technical Manual (TM) 5-330, does not provide a medium by which soil resistance data can be accessed quickly and efficiently. In addition, the TM mentions the likelihood of human error in properly recording data.

Technological advancements in electronic instrumentation and automation provide a means by which the manual control currently used in the conduct of military cone penetration tests can be reduced. Automation of the cone penetrometer testing operation provides a means by which the military ground units can obtain accurate soil resistance data in a quick and effective manner. In addition, the reduction in manual tasks required of the operator decreases the possibility of human error in the acquisition of soil resistance data.

In an attempt to overcome the shortcomings of the current device and to take advantage of some of the technological advancements in the field of in-situ testing, this research is centered around developing and testing an automated military cone penetrometer. The scope of this research is to provide a reliable tool in which the military's ability to gather soil in-situ data is much more efficient and in line with current practice in this field of engineering. The primary objectives of this research program include:

(1) Establishing the design performance requirements and constraints required of an automated military cone penetrometer system and working closely with the U.S.

Waterways Experiment Station in the physical construction of this system.

(2) Establishing an effective and efficient means of interpreting the electronically acquisitioned soil resistance and depth of penetration data through the use of an electronic spreadsheet.

(3) Developing an Operator's Manual for the use of the automated system in the conduct of trafficability studies and soil profiling.

(4) Developing and conducting a laboratory testing program in Chattahoochee River Sand to validate the proposed automated cone penetrometer system.

(5) Qualitatively analyzing the effects of rate of penetration, cone size, and concentrated surface loading conditions on soil resistance data obtained with the automated system.

(6) Roughly comparing the soil resistance data obtained with the automated system during the laboratory testing program with the soil resistance values obtained using the analytical model developed at the Waterways Experiment Station by Baladi and Rohani

(1981). It is noted that a detatiled study of this aspect is not within the immediate scope of this research.

(7) Developing and conducting a field testing program to establish the system's ability to effectively measure soil resistance in a realistic, variable soil mass. This variability may be due to either the inherent material composition differences or to the development of a dessicated crust on the surface of an otherwise relatively soft deposit of soil.

(8) Establishing the capability of the automated system to effectively measure the change in soil resistance in a soil mass subjected to repeated loading conditions which simulate vehicle traffic.

A brief presentation concerning the use of the current cone penetrometer in the conduct of military trafficability studies will initially be provided to establish the need and requirements for the development of an automated cone penetrometer. Following this discussion, the remainder of the report will deal with the actual design, development, laboratory testing, and field testing of the proposed automated cone penetrometer system.

CHAPTER 2

BACKGROUND ON THE MILITARY CONE PENETROMETER

2.1 INTRODUCTION

The success of military maneuver operations, where movements on non-paved surfaces are required, depend heavily upon the subsurface soil conditions in the area of operation. As specified by the United States Army Technical Manual (TM) 5-330, a great majority of this success is based upon the proper determination of the soil's trafficability through the conduct of trafficability studies. This manual defines a soil's trafficability as its ability to support sustained military vehicle traffic. In determining the soil's trafficability capacity, the military has adopted a procedure by which in-situ and remolded strength parameters provide the impetus to designating the ability of a soil to support a given military vehicle.

To establish a soil's in-situ and remolded strengths, the United States Armed Forces utilize the standard military cone penetrometer. The standard cone penetrometer has been used by the military since the late 1950's to establish these properties and subsequently a soil's trafficability. This chapter will present the components and operational steps involved in the use of the conventional military cone penetrometer. An overview of how this device is used in the conduct of military trafficability

studies will presented. The efficiency and effectiveness of this particular device in the conduct of these studies establish specific shortcomings of the overall process. These shortcomings collectively establish the major reason for the need to conduct research for developing and testing an automated military cone penetrometer. Therefore, this chapter will conclude by incorporating this need for research into the discussion of the shortcomings associated with the conventional system.

2.2 STANDARD MILITARY CONE PENETROMETER

This section presents the components of the standard cone penetrometer presently being used by the military in the conduct of trafficability studies. Following this description of the device, a discussion of the current procedures required in its operation will be presented.

2.2.1 Components of The Standard Military Cone Penetrometer

The standard military cone penetrometer consists of a proving ring, a micrometer dial, a handle, a 30 degree right circular cone with a base area of .5 square inches, and an aluminum staff 19 inches long and 5/8 inch in diameter. Figure 2-1 depicts this device. In addition, this figure shows a 30 degree right circular cone with a base area of .2 square inches attached to a 3/8 inch diameter staff which can also be used to

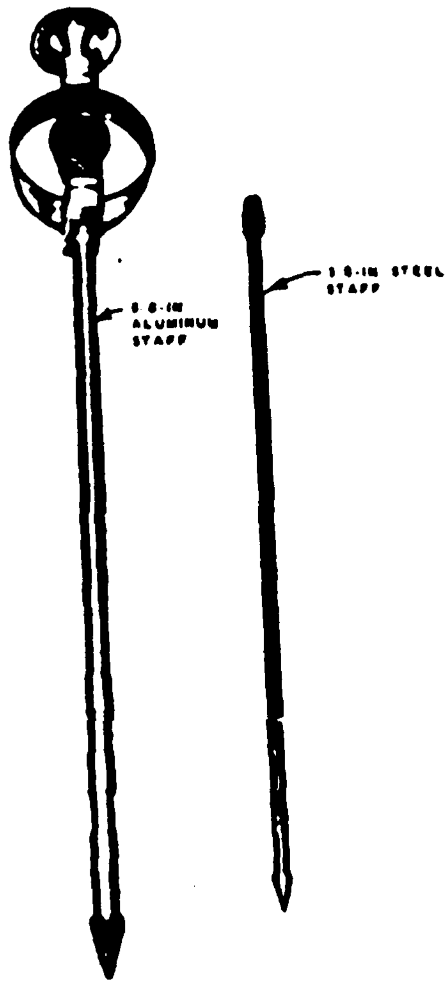


FIGURE 2-1   STANDARD MILITARY CONE PENETROMETER

conduct soil penetrations. The proving ring dial has a maximum capacity of 150 pounds which means that cone penetration data up to 300 psi can be measured with the .5 square inch cone and 750 psi with the .2 square inch cone.

2.2.2 Steps In Use of the Standard Military Cone Penetrometer

This section will present the procedures which have been thoroughly tested and adopted for the use of the standard military cone penetrometer in measuring soil resistance. Based on the components of the standard device presented in the previous paragraph, it is obvious that the operation of this device and the measuring of soil resistance must be accomplished manually. The shortcomings associated with the current device and to be presented later in this chapter stem mainly from the way in which these manual operational steps are conducted. Thus, a clear understanding of the current procedures followed in operating the standard cone penetrometer will aid in establishing the need to conduct the research for the development of the proposed automated military cone penetrometer.

The steps involved in the operation of the standard proving ring cone penetrometer system, as presented in TM 5-330, have been established to accommodate the possibility that there will be a single operator of the device. These operational steps are as follows:

(1) The hands of the operator, palm down and at approximate right angles, are placed over each other on the handle.

(2) Force is slowly applied by the operator causing a steady downward movement of the device.

(3) The first reading is taken from the micrometer dial just as the base of the cone becomes flush with the surface of the soil mass. To accomplish this, the operator closely watches the cone as it slowly descends into the soil mass, and at an instant just before the base of the cone becomes flush, the operator quickly shifts attention to the dial face.

(4) The force causing the slow downward movement of the cone is continued and the operator takes successive dial readings at 6 inch depth intervals throughout the established critical depth of interest. The TM states that "the rate of progression recommended is such that four readings (surface, 6, 12, and 18 inch) can be measured in 15 seconds in a continuous penetration in a soft soil."
The operator is allowed to temporarily stop the penetration after reading two values so as to allow the readings of cone resistance and corresponding depth to

be manually recorded. The penetration is then resumed to insure readings of cone resistance are measured to a critical depth. An assistant could be assigned to the operator which would facilitate this step by increasing the speed and accuracy with which these measurements are accomplished.

It is noted that the military has established critical depths of interest based on vehicle type and weight. These depths of interest range from as small as 3 inches to as great as 18 inches (TM 5-330). Research at the Waterways Experiment Station notes that the critical depth of interest may be as great as 24 inches which is in excess of the capability provided by the conventional cone penetrometer (Baladi and Rohani, 1981). In addition, the strength of some soils may require that intermediate values of cone resistance be established. The TM allows for these value to be interpolated based on the readings obtained at the 6 inch intervals.

2.3 USE OF THE CONE IN ACCOMPLISHING TRAFFICABILITY STUDIES

The basic unit in establishing the trafficability of a soil as related to military vehicles is the undimensioned quantity designated as the cone index. The cone index is a value which indicates the shearing resistance of the soil as it is subjected to the penetrating cone. This value of cone index is obtained by

dividing the force in pounds required to cause the cone to penetrate the soil by the base area of the cone in square inches thus establishing that this index, in actuality, has units of pounds per square inch. The in-situ cone index is read directly from the micrometer dial gage which is calibrated for either the .5 or .2 square inch cone and recorded in accordance with the procedures presented in the previous section.

In establishing the true strength of a soil, the military does not depend solely upon this value of in-situ cone index. As stated in TM 5-330, "Since the strength of a soil may increase or decrease when loaded or disturbed, remolded tests are necessary to measure the gain or loss of soil strength to be expected under traffic" (pg. 9-2). Therefore, the military has developed a procedure by which to remold the soil and subsequently measure the remolding cone index of the soil by using the cone penetrometer. This value of remolding cone index is then multiplied by the in-situ cone index to establish what is considered the true capacity of a soil to support sustained vehicle traffic. The true capacity of the soil is termed the rating cone index.

The final step in accomplishing trafficability studies is to compare the soil's rating cone index to the value required for the military vehicles in question. To accomplish this task the military has assigned each class of vehicle a vehicle cone index value which specifies the minimum soil resistance characteristic required of a soil mass to successfully support 50 passes of a

particular vehicle. These vehicle cone index values are tabulated for reference in Appendix C of TM 5-33Ø.

The remainder of this section will explain the various facets involved in obtaining the cone index values needed to establish a soil's rating cone index and how this index is used to establish the trafficability of a particular area of operations.

2.3.1 The Remolding Cone Index

The remolding cone index is the ratio of the remolded cone index to that of the original cone index of the soil under investigation. Both the original and remolded strengths are determined from cone penetrations conducted in a cylindrical test sample of the soil. A piston-type soil sampler as shown in Figure 2-2 is used to extract these samples from the soil mass. The test sample is contained in a steel cylinder 2 inches in diameter and 8 inches high. The encased sample is mounted on an aluminum base and then the cone penetrometer is used to measure the original and remolded strengths of the soil.

The original strength of the sample is measured with the cone penetrometer by taking five cone index readings commencing as the base of the cone becomes flush with the surface of the soil sample and then at successive one inch depths to a final depth of four inches. The soil in the sample cylinder is then subjected to 1ØØ repetitions of a 2.5 pound drophammer falling 12

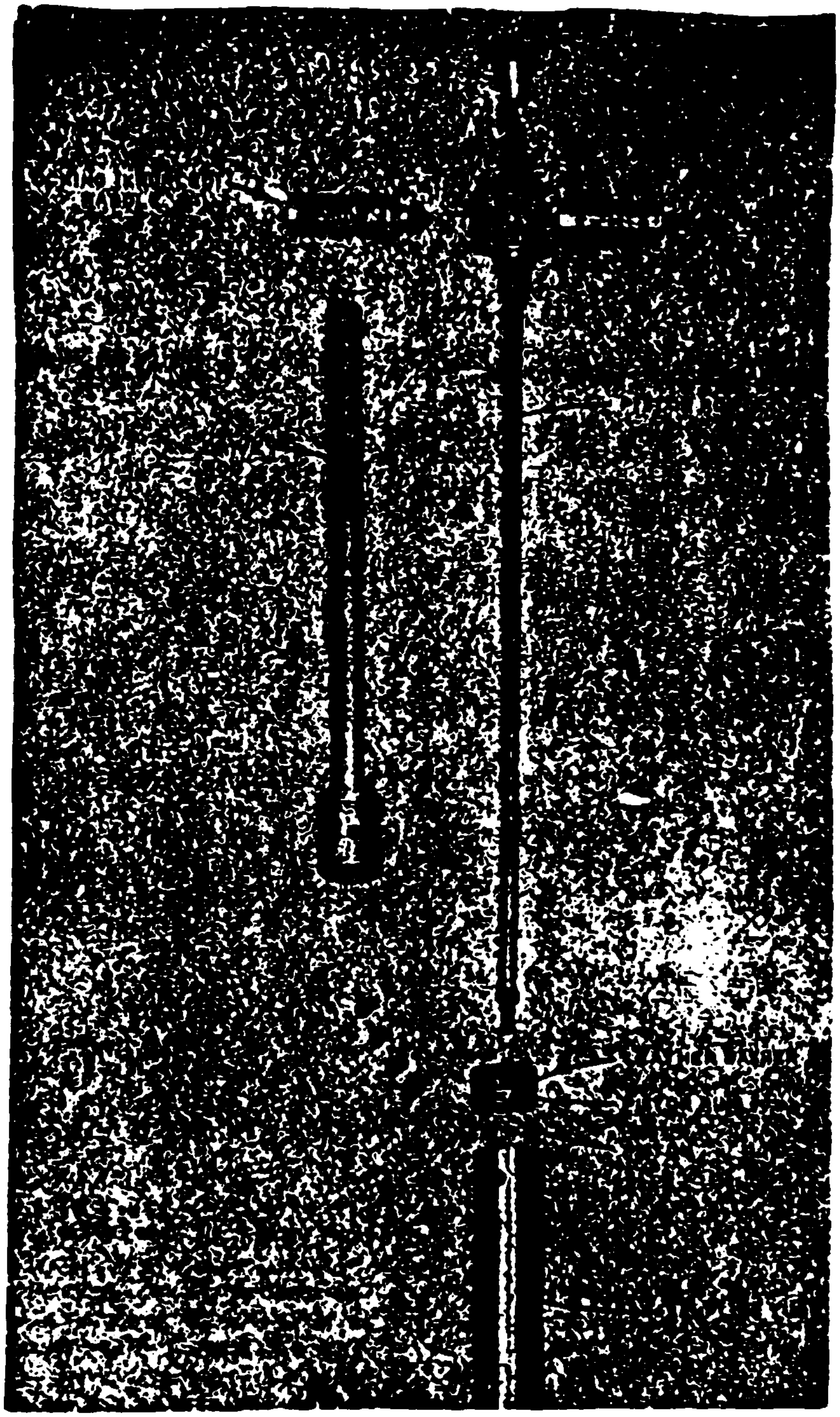


FIGURE 2-2 SOIL SAMPLER

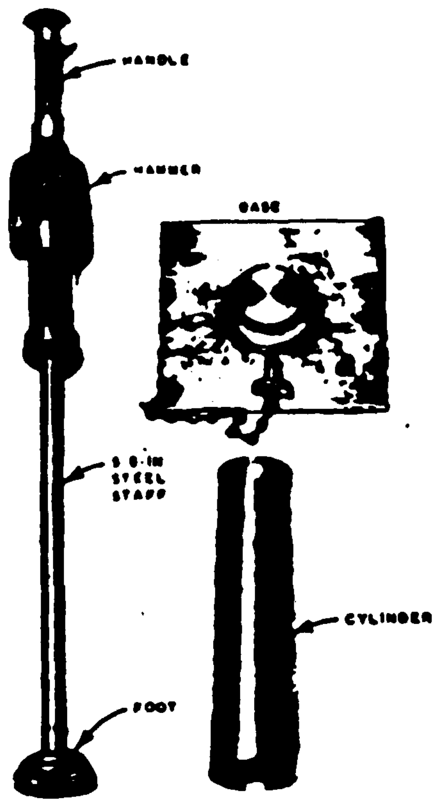


FIGURE 2-3 MILITARY SOIL REMOLDING KIT

inches to create a remolded sample. A remolding kit as shown in Figure 2-3 is used to prepare the sample needed for these penetrations. Following the loading conditions, the remolded strength of the sample is measured with the cone penetrometer by taking readings at the same locations as were used in determining the original cone index. The sum of the five remolded cone index readings divided by the sum of the five cone index readings recorded before remolding establish the remolding cone index of the soil.

2.3.2 The Rating Cone Index

The rating cone index establishes the strength rating of the soil under investigation when subjected to sustained military traffic conditions. This index is quantified by multiplying the measured in-situ cone index of the soil mass by the remolding cone index of the soil sample. Once the rating cone index of a soil mass is determined, the trafficability of an area of operations can be established by comparing this index to the vehicle cone index of the military vehicles required to traverse the terrain. If the rating cone index is greater than or equal to the vehicle cone index of all the military vehicles involved in an operation, then the soil mass is considered to be trafficable and suitable for such a military operation.

2.4 NEED FOR AN AUTOMATED MILITARY CONE PENETROMETER

Regardless of the fact that the use of the standard cone penetrometer has proven successful for some 25 years in the completion of military trafficability studies, there are certain inherent shortcomings associated with the use of this device in fulfilling this capacity. The researcher proposes that most of these shortcomings stem from the mere fact that this manual system is archaic and has not been improved since its inception in the late 1950's. In addition, current technology and theoretical research for quasi-static cone penetration testing indicates that the currently employed interpretation systems do not fully exploit the cone penetration test capabilities. It may indeed by possible to extract a considerable amount of soil resistance data from the test by altering the test equipment slightly. The purpose of this section will be to present these shortcomings and establish the basis upon which the need to conduct the research in developing and testing an automated military cone penetrometer is founded.

2.4.1 Reading and Recording Data

The procedural steps presented in sections 2.2 and 2.3 concerning the use of the cone penetrometer in the conduct of military trafficability studies paint a picture that the overall technique is extremely labor intensive. Without the aid of an

assistant, the operator of the cone penetrometer is required to accomplish many simultaneous tasks to arrive at the proper cone index value. Specifically, the operator must push the cone penetrometer, watch the dial gage and be aware of the depth of penetration all at the same time to insure that readings are properly recorded. The recording of this data may mean that the operator remember two to three cone index values and their corresponding depths before actually recording them in writing. The presence of an assistant facilitates the recording of data; however, the task is still labor intensive and extremely dependent upon the proficient skill of the operator, the procedures used to conduct the test, and the assistant. In fact, TM 5-330 states:

> "If readings are actually made as little as one-quarter inch from the proper depth and recorded as being at the proper depth, an average of such readings will not accurately reflect the average strength at that depth. Carelessness in making proper depth determination is probably the greatest source of error in the use of the penetrometer."

The accuracy of cone index readings is paramount in the proper determination of a soil's trafficability and, as stated above from the TM, the accuracy of these readings is dependent upon the ability and attention to detail of the particular

operator or team. Other details not thoroughly considered in the TM, such as: (a) rate of penetration, (b) time between cone advances, (c) eccentric loading, and (d) disturbance induced by the operator in preparing and testing the soil may significantly effect the derived cone index values as well. From this discussion, it is obvious that human error and operator induced effects are probably the major cause for not being able to properly record reliable data. Therefore, if the tasks currently required of the operator are reduced and operator induced testing effects are taken into account, then the quality and value of the data should be enhanced.

This need to reduce the possibility of human error and the potential to extract much more qualitative data from the cone penetration test are the major reasons for the development of an automated system. An automated military cone penetrometer designed to automatically record the soil resistance and corresponding depth of penetration data would reduce the number of tasks currently required of the operator and insure that the data is recorded accurately. Such a system would enable the operator to only be concerned primarily with the task of pushing the device and keeping it vertical during a penetration test. In addition, this reduction of the labor intensive tasks would increase the efficiency of the whole operation by reducing the amount of time required to conduct a penetration test.

2.4.2 Effective Soil Profiling

The concluding discussion of the previous subsection demonstrated the need for an automated military cone penetrometer in order to minimize the effects of the operator on the derived soil condition. A second rationale for the development of the automated system concerns both quality and use of the data from the penetration test.

As stated in section 2.2.2, TM 5-330 allows for intermediate cone index values between the recorded 6 inch interval values to be interpolated. The allowance for this interpolation is to better define the underlying soil conditions. In addition, Baladi and Rohani (1981) state that military cone index readings should be obtained usually at 1 inch intervals throughout the prescribed critical depth of penetration to effectively establish the soil profile in the conduct of trafficability studies. They further state that the maximum critical depth of penetration for military operations should be around 24 inches. Therefore, both the military's Technical Manual and the work by Baladi and Rohani, establish the need to gather soil resistance data in greater detail than is presently required in order to better define a soil's profile. Furthermore, the recommendations from these two sources are extremely difficult to utilize and incorporate using the conventional system.

Using the standard proving ring system to obtain a sufficient number of cone index readings to meet the above

objective would be very time consuming as the amount of manually recorded data would increase dramatically. Such an increase in required readings with the standard proving ring device would also increase the possibility of human error as discussed in the previous sub-section. Therefore, the development of an automated system that is configured to record resistance data at successive one inch intervals would effectively and efficiently accomplish the requirement established by Baladi and Rohani and alleviate the need for interpolation established by the TM. The beauty of such an automated system is that it provides an effective and quick manner in which a continuous soil profile of the soil mass under investigation can be obtained.

2.5 SUMMARY

This chapter has presented the overall process currently followed in the conduct of trafficability studies to establish a soil's capacity to support military vehicle traffic. It is proposed that these current procedures and the equipment provided to accomplish this task are not sufficient to meet the specific needs of military units on the highly advanced modern battlefield. Specifically, the proving ring cone penetrometer system is out of date with current technology in the field of in-situ cone penetrometer testing. The military depends on this antiquated equipment to provide them with the data needed to insure trafficability of some of the most technologically

advanced pieces of military equipment in the world. It would be a shame if the shortcomings noted with this manually operated cone penetrometer should hamper the capability of these highly advanced vehicles to successfully accomplish their mission. Therefore, this system presents shortcomings which must be addressed and corrected to insure that the United States Armed Forces are able to exploit their highly advanced equipment effectively.

In an effort to overcome the shortcomings associated with the proving ring cone penetrometer, an automated system was developed and tested in the conduct of this research. The automated military cone penetrometer was developed based on the need to improve the effectiveness and efficiency of obtaining soil resistance data in the conduct of trafficability studies. The proposed automated system takes advantage of some of the current technological advancements in the fields of in-situ cone penetrometer testing and automated data acquisition techniques. The following chapters in this report will present the development, design, and testing conducted in establishing the capabilities of the automated military cone penetrometer.

CHAPTER 3

AUTOMATED MILITARY CONE PENETROMETER

3.1 PURPOSE OF THE AUTOMATED SYSTEM

As mentioned in the previous chapter, the operator of the standard military cone penetrometer is required to accomplish many tasks during the performance of cone penetration operations. The feasibility of such a labor intensive procedure is questionable; and thus, the need to relieve the burden of the operator in the data gathering process and to make the overall cone penetration operation more effective and efficient is established. Specifically, this means getting more exact data for geotechnical purposes to identify the soil, its strength properties, and its performance aspects in trafficability studies.

This need to facilitate the data gathering process led to the design of the automated system presented in this chapter. This automated system establishes the means by which an efficient and feasible data acquisition system can be employed to improve the data gathering process of soil resistance and depth of penetration involved in cone penetration operations. Thus, the system presented in this research provides a simple mechanism by which a greater quantity of precise data can be retrieved in a much shorter time period than previously occurred with the old

system.

Following a discussion of the constraints and performance requirements which were applied in developing the design of this system, a general discussion of the developed automated military cone penetrometer system will be presented. Subsequent sections will then present the particular aspects of the various components which make up the automated cone penetrometer system. The final section will discuss how data is retrieved from the apparatus and utilized for analysis.

3.2 DESIGN PERFORMANCE REQUIREMENTS AND CONSTRAINTS

The automated data acquisition system designed for the military cone penetrometer was developed with the major objective being to provide the military with a more effective and feasible means to conduct cone penetration testing. As noted in Chapter 2, TM 5-330 indicates that one of the major sources of error in cone penetration testing is the proper annotation of the depth of penetration and the corresponding cone index value. Therefore, the focal point of the objective in this research was to develop a procedure by which to eliminate the conventional technique of annotating data by hand and to replace this technique with an automated data acquisition system. In establishing this overall objective certain inherent performance requirements and constraints for the automated military cone penetrometer system were fostered prior to the apparatus' actual development.

The first constraint was that the system should remain

portable and capable of being a one person operation. Therefore, as many of the components as possible from the conventional system were utilized without significantly changing the overall size and weight of the apparatus. One small change was that the length of the shaft was fixed at 30 inches to accommodate a 24 inch maximum critical depth of penetration as discussed in Chapter 2. The major change in establishing a one person operation scheme was the development of an automated data acquisition system. This required that a self-contained data acquisition system be developed which could easily be transported and attached to automatically gather data. This led to the development of the instrumentation package to be further discussed in the next section.

Another constraint was the need to provide a data acquisition system capable of gathering data on soil resistance which would be compatible with the military's current published data base utilized in establishing a soil's trafficability characteristics as discussed in Chapter 2. This detailed that the position of the load cell be such that it would model closely the performance of the proving ring and dial system used in the conventional method. Therefore, the load cell needed to be positioned between the cone penetrometer handle and shaft. In addition, the conventional proving ring and micrometer dial system has a capability of measuring a maximum applied force of 150 pounds thus establishing the need to provide a load cell with at least equal capacity. A 200 pound load cell was ultimately

placed in the automated system. The size of the load cell was based mainly on supply and the need to conduct laboratory testing where a capacity greater than the 150 pounds may be needed.

Along with the need to obtain soil resistance data was the requirement to automatically gather the corresponding depth of penetration. A linear potentiometer or string pot was placed in the device to provide this capability. The basic constraint on the potentiometer was the need to obtain data to a minimum depth of penetration of two feet. The final active length of the wire utilized was 27 inches which provides a free play of three inches for maneuverability and to aid in reducing the likelihood of damage to the potentiometer by overstretching or breaking the wire.

The presence of the potentiometer entailed the requirement to provide a mechanism by which the wire could be anchored during testing. The mechanism chosen was that of the foot rest. The foot rest not only provides an anchor for the wire of the potentiometer but also establishes a standard for the operator to position his feet. The position of the feet during the conduct of cone penetration testing with this device could be a key factor in obtaining correct soil resistance values as will be further discussed in the results section of the laboratory testing program in Chapter 5.

With the means of measuring the soil resistance and depth of penetration established, the requirement of conditioning and logging this data was undertaken. This established the need for

a data logger. The performance requirements placed on the data logger were as follows:

- portable and small enough to establish a self-contained system that could be operated by one person.
- sensitive enough to gather and store soil resistance and depth of penetration data at an interval of .25 inches over a depth of 24 inches at a rate of penetration of 1.2 inches per minute.
- sensitive enough to establish extreme changes in the CI during penetration testing.
- low power drain.
- capable of storing data from numerous cone penetrations.

The United States Army Corps of Engineers at the Waterways Experiment Station (WES) in Vicksburg, Mississippi, was in the process of conducting various experiments where the need to utilize a data logger was being undertaken. The experience, knowledge and ability of the personnel at WES to construct a signal conditioning system and utilize a data logger was tapped to aid in the final design and to provide construction of the self-contained instrumentation system snown in Figure 3-1.

The data logger board chosen to provide the brains to the automated cone penetrometer was the 'Model IV Tattletale Data Logger' produced by the ONSET Computer Corporation. In general, the Tattletale is a pocket sized, lightweight, and battery based device with a built-in BASIC operating system for data gathering capabilities (Tattletale, 1987). Further discussion of the

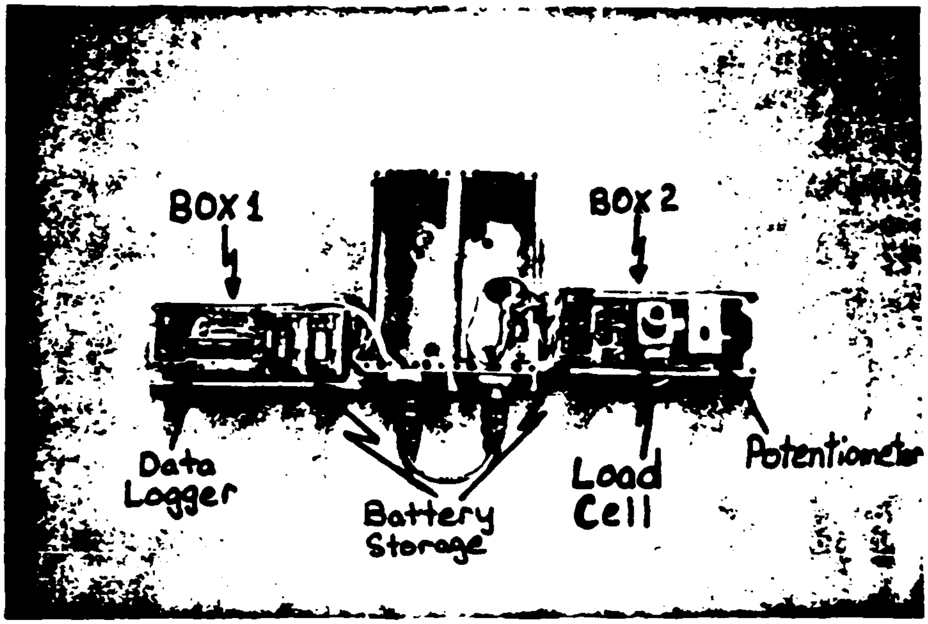


FIGURE 3-1 SELF-CONTAINED INSTRUMENTATION SYSTEM

particular aspects of the data logger will be presented in subsequent sections of this chapter. The small size and tremendous capabilities of the Tattletale enabled the final fabrication of the automated data acquisition system to be successfully completed.

The completion of the automated data acquisition system required that the apparatus be functionally easy to understand and operate. Therefore, the final step in the design of the automated system was the concurrent development of the control board, located on top of box 1, and of the computer program. The computer program which is placed in the data logger is the key element in establishing simple, efficient and effective control measures throughout the automated cone penetration operations. With the completion of the instrumentation boxes, the control measures, and the computer program, an automated military cone penetrometer was developed that facilitates the data acquisition process of soil trafficability studies in military operations.

3.3 GENERAL DESCRIPTION OF THE AUTOMATED CONE PENETROMETER

The automated military cone penetrometer utilizes the same 3/8 inch steel shaft (except 30 inches in length), cones (.2 and .5 square inch base area) and handle provided for the standard cone penetrometer as presented in Chapter 2. The proving ring and dial have been replaced with two electrically instrumented boxes. A foot support with washer has been added. Figure 3-2

depicts these components of the automated cone penetrometer system. It is noted that, based on the design requirements established by the researcher and as stated in section 3.2, personnel at the WES designed and constructed the details of the electronic instrumentation used in this device.

The two separately instrumented boxes are secured to a common metal plate forming what is called a self-contained instrumented system made of hard plastic which encases a load cell, potentiometer, and data logger with signal conditioning. The self-contained instrumented system measures 7.5 inches in length, 6 inches in width, and 3 inches in height. These components of the instrumentation provide the means by which data for the soil resistance, penetration distance and rate of penetration are automatically gathered and stored for analysis. Further discussion of the specific details of these individual components, which comprise the data acquisition system, will be presented in section 3.4.

As mentioned above, the self-contained system consists of two separate boxes and each serves a specific purpose in the operation of the automated military cone penetrometer. As depicted in Figure 3-3, the boxes have been numbered for easier reference in the discussion to follow. Box 1 consists of a top with various operational control knobs and windows which are utilized by the operator throughout the process of cone penetration testing to accomplish specific functions in gathering and analyzing penetration data. Through the manipulation of

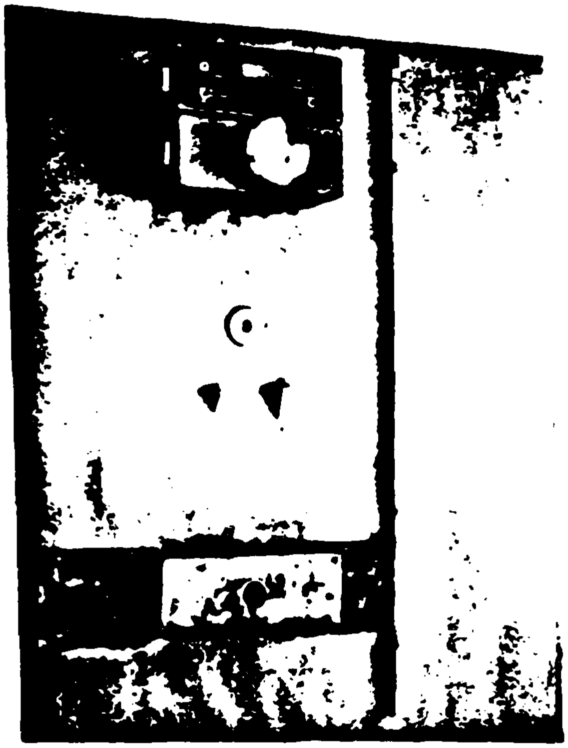


FIGURE 3-2 COMPONENTS OF AUTOMATED MILITARY CONE PENETROMETER

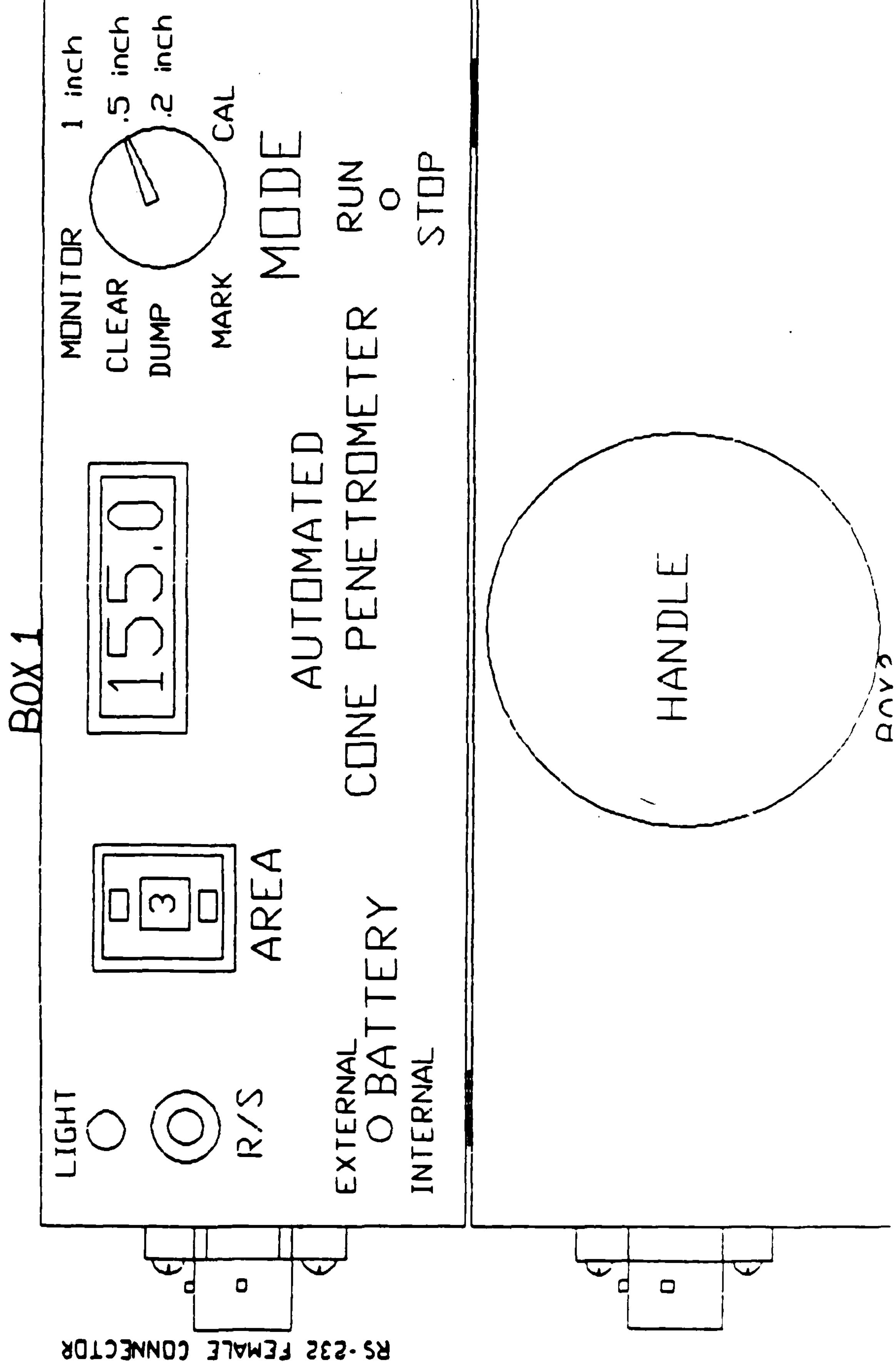


FIGURE 3-3 TOP VIEW OF INSTRUMENTATION BOXES

these controls the operator is able to communicate with the computer program in the data logger to specify a desired function.

Box 2 encases the load cell, potentiometer and power source required for these two measuring instruments. Located at the top of box 2 is the standard cone penetrometer handle which is attached to the load cell inside this box. The 30 inch shaft is attached to the other end of the load cell at the bottom of box 2, and the potentiometer string, which protrudes from an opening in the bottom of this box, is attached to the foot rest as shown in Figure 3-4. To complete the configuration of the automated military cone penetrometer, the washer is placed on the shaft and the cone of selected size is attached to the end of the shaft. The washer is placed between the foot rest and the cone to aid in limiting vertical deflection and thus decrease the possibility of overstretching or breaking the potentiometer string. Figure 3-5 shows the automated cone penetrometer in the operational mode with all attachments and components in place.

The specific purpose of the control knobs and the functions that the automated military cone penetrometer is capable of performing will be discussed in the following sections of this chapter. The operational use of the automated cone penetrometer in accomplishing the specific functions entailed in cone penetration testing is presented in Appendix A, "OPERATOR'S MANUAL". This manual provides a step-by-step procedural outline for the operator of the automated military cone penetrometer to

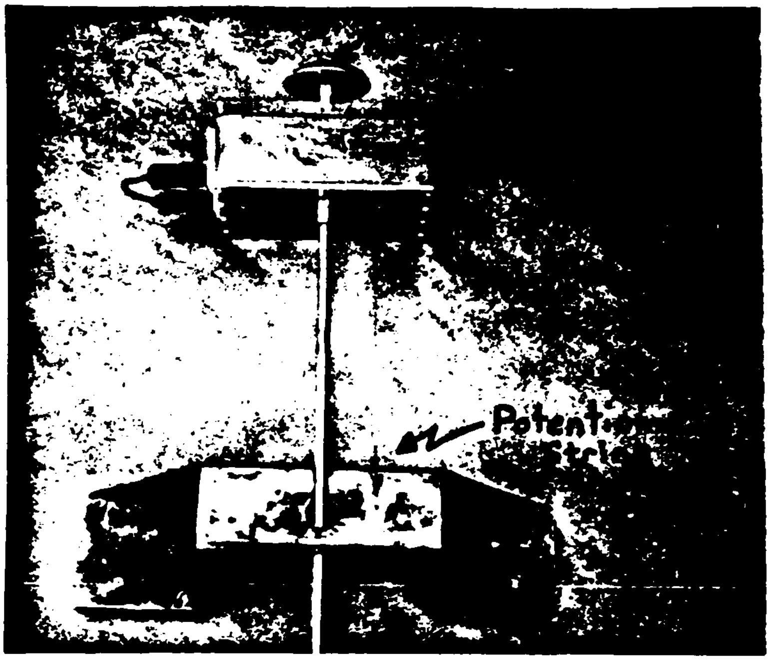


FIGURE 3-4 POTENTIOMETER STRING ATTACHED TO FOOT REST

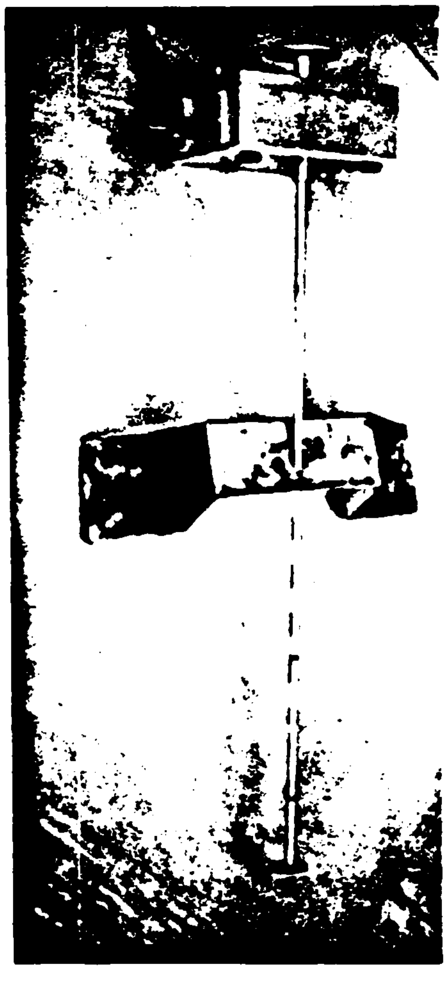


FIGURE 3-5 AUTOMATED MILITARY CONE PENETROMETER SYSTEM

follow in performing any of the functions available for the apparatus. The manual was prepared separately to provide a stand-alone reference document for the military operator.

3.4 COMPONENTS OF THE AUTOMATED DATA ACQUISITION SYSTEM

This section will discuss each of the major components which make up the data acquisition system of the automated military cone penetrometer. The specific details and features of each of these components will be presented separately.

3.4.1 The Load Cell and Potentiometer

The automated cone penetrometer system utilizes a 200 pound capacity load cell for electrically measuring the vertical force applied to the penetrometer handle during penetration testing. The placement of the load cell between the cone penetrometer handle and shaft is not in agreement with current technology utilized by the manufacturers of the commercial electric-friction cones. These commercial cones follow the impetus that there is a need to measure the bearing capacity of the cone tip and the friction on the sleeve separately. This is accomplished by placing the electrical measuring devices within the cone and on a frictional sleeve along the shaft.(Chourey,1984) Even though the need for such techniques in measuring have been established, the requirement of the automated cone penetrometer to maximize

utilization of the extensive data base which already exists for the standard military cone penetrometer in establishing soil trafficability is overriding at the present time.

A linear potentiometer is utilized in the automated military cone penetrometer to electrically measure the depth of penetration. The wire on this device has an extended length of 27 inches and as previously presented, this length meets the specified requirement to obtain data to a critical depth of 24 inches during the conduct of a penetration test.

Referring back to Figure 3-1, the power source requirements of the load cell and the potentiometer located in box 2 are supplied two common size 9 volt transistor batteries. As shown in the figure, these batteries are located in secured slots within the box. The present apparatus makes no provisions by which these batteries can be recharged nor switched off externally. Such a design causes the load cell and the potentiometer to drain the power source below an acceptable level within a very short time. Therefore, the researchers at Georgia Tech were continuously having to remove the top of box 2 and change the batteries every four to six hours to insure proper measurements by the load cell and the potentiometer. The location of the batteries inside the box with no provisions of external control for switching the power off and for recharging them is noted by the researcher as a major shortfall in the present design of the apparatus.

3.4.2 The Data Logger

As stated previously, the data logger board chosen to provide the brains to the automated cone penetrometer was the 'Model IV Tattletale Data Logger' produced by the ONSET Computer Corporation. It is noted that the majority of the information concerning the specific details of this device and as presented in this section are summarized from the Onset Corporation's reference manual for the Tattletale Data Loggers.

The Model IV Tattletale data logger provides an 8K Random Access Memory which is expandable to 512K, an interface of 16 digital input/output lines, an eleven channel analog to digital converter, hardware for universal asynchronous receiver/ transmitter (UART) operations, and voltage regulation of 7-15 volts input and 5 volts ($\pm$3%) output (Tattletale, 1987). Figure 3-1 shows that the Tattletale is located in box 1 and connected to an interface board designed for the automated military cone penetrometer by WES.

The Tattletale is configured with connections at six locations: one at the 9-volt battery connector, one at the 9600 baud modular connector (UART), and four at locations which connect to the interface board. The Tattletale is connected to the interface board which will condition the analog and digital signals coming in and leaving the board by use of 0.025 inch square pins. As shown in Figure 3-6, the Tattletale data logger consists of 36 connection points divided between the analog,

digital and serial Ø.Ø25 inch pins, five at the power pin sockets, six at the UART and two at the connection point for the 9-volt battery.

The eleven channel analog to digital converter on the Tattletale possesses a 1Ø bit resolution. The channel numbers and locations are as depicted in Figure 3-6 and only channel eleven (A1Ø) has been preassigned (contains a thermistor) leaving the other ten analog inputs undedicated. The converter makes ratiometric measurements which are relative to the supply voltage from the interface board. In the automated cone penetrometer design presented for this research, only channels Ø and 1 were used. Channel Ø is used for reading the soil resistance in pounds of force measured by the load cell and channel 1 is used for reading the depth of penetration in inches measured by the linear potentiometer. The instrumentation within the automated system is configured to amplify and filter the analog inputs from these devices before being attached to the Tattletale converter.

Each of the 16 digital input/output lines on the Tattletale is available for use as either an input or output depending on how the logger has been programmed. The Model IV Tattletale's only requirement is that Pin #4 (D4) be placed in a logic high mode at power up to insure that the Tattletale board will turn-on. An interface board was designed at the Waterways Experiment Station in Vicksburg, Mississippi, for signal conditioning and additional input/output capability by making contact to the Ø.Ø25 inch pin strip digital connections shown on Figure 3-6. The

specified function of each of the sixteen pins in the current design of the automated cone penetrometer are as follows:

Pin #0: R/S Button

Pin #1: Run/Stop Switch

Pin #2: Liquid Crystal Display (LCD)

Pin #3: Not Used (Set High in Program)

Pin #4: Not Used (Set High in Program)

Pin #5: LCD

Pin #6 through #8: Mode Selector Input (Multiplex)

Pin #9: Mode Selector Output (Multiplex)

Pin #10: Lightbulb

Pin #11: LCD

Pin #12 through #15: Thumbwheel for Area

A multiplex configuration was utilized to provide additional input/output capability of the Mode Selector Switch. This multiplex is configured to use pins 6,7 and 8 as inputs and pin 9 as an output to provide this additional capability in the use of the Mode Selector Switch.

The UART, modular hardware has been programmed to run at 9600 baud, eight data bits, one stop bit and no parity. The RS-232 interface cable uses a six pin modular connector to connect to the UART at one end while the other end "has a female 25-pin D-subminiature connector" allowing direct connection to an IBM or compatible computer's serial port for communications' capability. The drivers for the RS-232 are located inside the interface cable thus establishing what is called a TC-4 cable by

the ONSET Corporation. Figure 3-7 shows the TC-4 communications' cable connections.

The Tattletale is configured with a connector to accommodate a common 9-volt transistor battery. To insure proper operation of components, the Tattletale Model IV requires 7-15 volts for an input range and 5 volts (±3%) for output. The control box, box 1, in the automated cone penetrometer design is configured with an external ON/OFF Switch on the control panel to prevent excessive drainage of the 9-volt battery supply.

The Tattletale's main power source is the 9-volt battery, and if this battery is removed or the voltage falls below 6.5 volts then the device will transfer to its lowest power mode. The Tattletale is also configured with an onboard 3-volt CR2Ø32 lithium battery which, as stated by the ONSET Corporation, should maintain the existing program and data in the device for approximately six months when the device is operating in the low power mode. Once the main battery is reconnected the Tattletale board will automatically restart the program at line 1ØØ due to internal configurations of the device's ROM. This automatic restart at line 1ØØ is a very important point which must be considered during the development of the computer program. In addition, it should be noted that if the external switch is turned OFF and the UART TC-4 cable is left attached to the Tattletale, then the life of the CR2Ø32 lithium battery is shortened tremendously. This excessive drainage is due to the fact that the drivers for the UART are located in the cable and

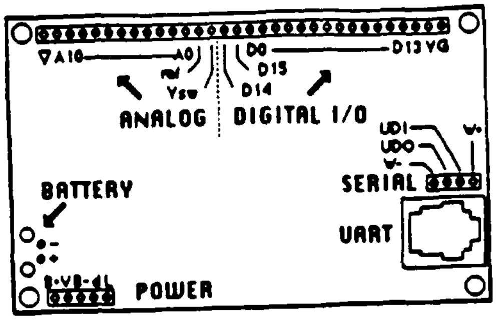


FIGURE 3-6 TATTLETALE DATA LOGGER
BOARD CONFIGURATION

(EXTRACTED FROM TATTLETALE REFERENCE MANUAL)

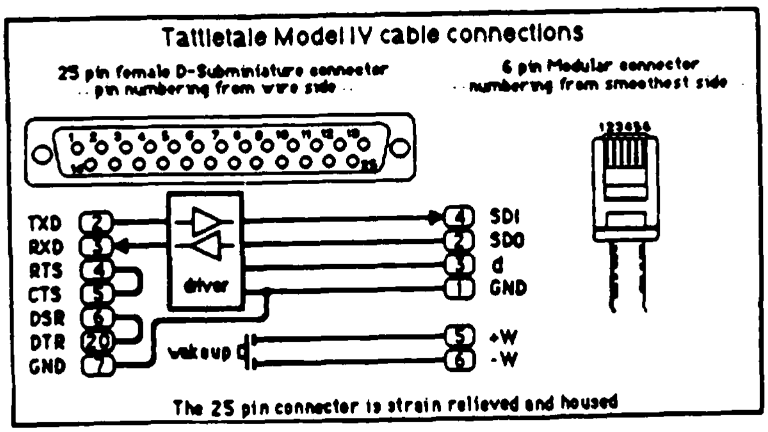


FIGURE 3-7
(EXTRACTED FROM TATTLETALE REFERENCE MANUAL)

are therefore continuously using the power of this battery.

A Liquid Crystal Display (LCD) has been incorporated into the control panel of the automated military cone penetrometer to provide the operator with visual information during the process of selected functions. The visual information is depicted in three situations. Two of these situations occur in the calibration function of the apparatus as the operator is able to visually check the load cell and potentiometer calibration by use of the binary digits depicted in the display. The other situation is when the actual force applied to the cone penetrometer is depicted on the display during the conduct of penetration testing in a soil. The designation of the three pins previously depicted for use of the LCD is in accordance with the ONSET Corporation's internal program development for the Tattletale data logger.

3.4.3 Features of the Computer Program

Basically, the computer program's development stems from the need to provide a system which is functionally easy to understand and operate and simultaneously able to provide more accurate data in a shorter time frame. Noted is the fact that, based on the performance requirements and constraints as presented in section 3.2 and specified by the researcher, the actual writing of the computer program was initially completed by personnel at WES and edited by the researcher. Since the operational controls desired

of the automated military cone penetrometer had a great influence on the computer program's development, a short discussion of each of these controls will be presented in conjunction with the discussion concerning the development of the computer program. The detailed operational use of these controls during actual automated cone penetration operations is presented in the **"OPERATOR'S MANUAL"** located in Appendix A.

The Model IV, Tattletale data logging device, utilizes an operating system called **TattleTale Beginners All-purpose Symbolic Instruction Code** (TTBASIC). This language provides the computer programmer with the opportunity to take full advantage of the simplicity of the BASIC language and the ability to modify it "to conform to the requirements of a low-power data logger." (Tattletale, pg.9) In addition to the discussion of the computer program's development, this section will also present the special features of the TTBASIC language utilized in the process. The computer program which was finally used for the basis of analysis in this research project is located in Appendix D for reference.

Specific features of the TTBASIC operating system establish certain aspects of how the computer program is to be written. First, the Tattletale will only communicate with "upper case" for all aspects of the program except for string constants and program remarks. Second, the device only supports integer constants. Therefore, no decimal points, commas or exponential constants are allowed. Decimal point values which may arise from arithmetic operations in a program will automatically be

disregarded and not stored. The development of the computer program for the automated cone penetrometer required that decimal point values be stored to an accuracy of two decimal places; therefore, arithmetic values were manipulated by constants to meet this requirement as shown in lines 9350 - 9430 of the program.

The computer program as depicted in Appendix D is separated into parts or subroutines to facilitate program development and editing procedures. The first 99 lines define the variables utilized throughout the program. As seen in the program, the Tattletale accepts a wide range of integer variables represented by the capital letters, variable integer arrays represented by the "@" symbol, and the "?" symbol for establishing time variables. Whenever any of these variables are changed, the Tattletale must be executed from the computer keyboard to insure that the program understands the change in variable values. The execution of the program requires that the operator **RUN** the program which causes the Tattletale to start the program from line 1 and thus redefine the variables. The reason for executing the **RUN** command from the keyboard when the variables are changed is based the previously noted point that the Tattletale will begin all operations beginning at line 100 unless commanded otherwise.

The variable designations are immediately followed by the subroutines, which comprise the main program. These subroutines are broken down by control measures/modes which have specific

lines designated to their use for completion of the particular function that the automated cone penetrometer operator desires. Following the procedural outline established in the Operator's Manual for a particular function, the cone penetrometer operator will cause the computer program to be activated and the specified function performed. The following paragraphs will analyze each of these specific functions in the computer program's listing.

Select Mode: The Mode Selector Switch is utilized to select the particular mode of operation which the operator desires to perform. As depicted in Figure 3-3, this switch is used to select from one of the following modes of operation: **Clear; 1, .5, or .2 Inch; Calibrate; Mark; Dump.** Line 31Ø executes this selection and directs the program to lines 5ØØ to 76Ø which define the mode that has been chosen by the operator. As shown in the program, lines 5ØØ to 7ØØ have been developed to supplement the multiplex, which was discussed previously.

Clear Memory: This function allows data which may be stored in the data storage arrays to be cleared from the memory of the Tattletale prior to further testing. After selecting the Clear mode of operation and following the procedures as outlined in the Operator's Manual for "Clearing the Memory" lines 3ØØØ - 3Ø9Ø will be executed in the computer program. Once this command is executed there is no way to retrieve any data which may have been stored in RAM prior to its execution.

1, .5, .2 Inch: This function on the Mode Selector Switch is utilized to designate the size of the right circular cone which is being utilized for a particular penetration sounding. Lines 570 - 680 establish whether the pins are set in a high or low position, thus designating which cone size has been chosen. When the hard copy data is finally retrieved/dumped from the data logger, the data depicts which cone was utilized by printing either a 6 or 7 for the .5 and .2 square inch cones, respectively. As shown in Figure 3-8, the CONE size for these particular penetrations designates a 7 which corresponds to a .2 square inch cone. It is noted that one shortfall of the current program is the fact that the variable designating the location of the base of the cone (line 56) must be redefined when alternating cone sizes. This redefining of the variable is required to insure that the initial reading of a cone penetration is measured as the base of the cone becomes flush with the soil surface.

Once the particular cone size has been established, the program is set to begin collecting data for an automated cone penetrometer test. Data collection is established in the subroutine which is represented by lines 5000 to 5450. These lines were developed with the intention of collecting continuous soil resistance and depth of penetration data and then storing the average of each. Specifically, the data logger is accepting continuous data from the load cell and potentiometer over a depth of .25 inches and then averaging these values over this depth to

establish one value of soil resistance which corresponds to a specific depth of penetration. The average soil resistance data point is then stored with the corresponding midpoint of the depth of penetration in the data logger by lines 7000 to 7220 of the computer program. It is proposed that the averaging of these values should provide a more realistic value for soil resistance.

In addition, the computer program utilizes the internal clock in the Tattletale to store time data points which correspond to the time at which the average data point is stored in the data logger (reference line 5290). Also, the light is turned on during the testing operation at line 5115 and then turned off to designate successful completion of the testing to the critical depth at line 5440. This determination of depth is provided by the depth of penetration readings which are measured by the potentiometer and transmitted to the data logger.

Calibrate: This function is utilized by the operator of the cone penetrometer to check the calibration of the automated data acquisition device which is presently being utilized. The load cell and potentiometer are calibrated to show a specific binary digit value in the LCD of the control box. The binary digit calibration value for the load cell was 2.35 binary per pound while the potentiometer's calibration binary digit was 23.93 binary per inch in this research. These values were then multiplied by a constant to keep the decimal point accuracy as seen in lines 70 and 72 for the soil resistance and depth of

penetration, respectively. The operator can check to insure that these binary digits are within tolerance by following the procedures as outlined in the Operator's Manual which execute line 41Ø and subsequently lines 6ØØØ - 6Ø7Ø. Any time that the load cell and potentiometer calibration values change, due to any maintenance operations on the device or replacement of measuring devices, then the computer program @ variables must be redefined accordingly. In addition, the program must be executed from the computer to initialize the new variables as stated previously.

Mark: This function allows the automated cone penetrometer operator the ability to "mark" a particular penetration for any reason. Such a condition may be exemplified by a penetration of the soil where the cone hits a rock at the 1Ø inch level and subsequently the rock breaks due to an increased applied force to the cone handle thus giving a full range of data over the critical depth of 24 inches. The data from such a penetration may be suspect and would possibly provide erroneous data unless designated by a **Mark**. Following the outline in the Operator's Manual, the operator causes the data logger to execute line 34Ø which subsequently executes lines 8ØØØ to 8Ø3Ø. Again, the computer program utilizes the light located on the control panel face to indicate to the operator that this function is being executed by turning the light on.

Dump: In general this function allows the automated

military cone penetrometer operator the ability to communicate with the Tattletale data logger. This function provides the means by which data is retrieved after the conduct of penetration testing and by which the computer program can be edited as needed. Detailed explanations of the required peripherals to insure proper communications capability between the Tattletale and the computer are discussed in the next section on data retrieval and in the Operator's Manual. Following the procedures outlined in the Operator's Manual for the Dump mode, the operator causes line 350 to be executed which subsequently executes lines 9000 to 9770. As seen in the computer program, lines 9000 to 9770 detail how the off-loading of data collected in the data files is to be accomplished. These lines were written with the intention of being able to retrieve data in a column format which could subsequently be manipulated for further analysis using an electronic spreadsheet such as LOTUS.

Lines 2000 to 2360 are utilized to develop the subroutine which executes the LCD. This procedure is in accordance with the specifications of the ONSET Corporation's User's Manual for the Tattletale. Also, lines 800 to 840 establish the position of the thumbwheel which designates the area which is being tested. The purpose for this switch is to provide the operator with a crutch in specifying work areas when multiple cone penetrations are to be made at various sites prior to the off-loading of data. The thumbwheel/Area switch is depicted on Figure 3-3 and can be

utilized to designate 1Ø different areas from Ø to 9. The position of the **Area** switch during penetration testing will be presented in the formatted data during the retrieval process.

3.5 RETRIEVING USABLE DATA

The requirements for the retrieval of data are broken into two general categories, that being retrieval and storage of data during penetration testing and retrieval of the stored data following the completion of penetration testing. The requirements for the retrieval and storage of data during the conduct of penetration testing were discussed in the preceding section concerning the computer program and are procedurally outlined in the **Operator's Manual** in Appendix A. Therefore, this section will concentrate on discussing the requirements for data retrieval from the Tattletale (data logger) at the completion of penetration testing.

3.5.1 Equipment Requirements

The Tattletale is capable of communicating with a wide variety of computer systems which include the APPLE, IBM, and compatible computers which are equipped with communications' capabilities. For the conduct of this research, two different computers were utilized: the IBM standard and the IBM Convertible. Any communications' software capable of accepting

the standard variables, discussed previously in the section concerning the UART, can be utilized to link the computer to the Tattletale. In the conduct of this research a communications' software program called MIRROR was used. The following paragraphs will discuss the particular attributes provided by the computers and communications' software and how these two devices are utilized to retrieve data from the data logger.

Both of the computer systems contained a standard dual floppy configuration with the IBM standard being equipped to support a third disk drive that accepts a 3.5 inch disk. The need for the 3.5 inch disk drive is twofold. First, an initial requirement of the automated system was that it be fully capable of being transported to the field in the most efficient manner possible. This requirement led to the utilization of the IBM Convertible computer which is easily transported and can facilitate the function of retrieving data in the conduct of cone penetration operations in a field environment. The convertible computer utilizes a 3.5 inch disk; therefore, to take advantage of the speed offered by the IBM standard, which utilizes 5.25 inch disks, the external 3.5 inch disk drive was added to facilitate the evaluation process of retrieved data. Second is the amount of storage capacity available on a 5.25 versus a 3.5 inch disk for data retrieval. Basically, the 3.5 inch disks provide 720k of storage capacity which is twice as large as the 5.25 inch disk which provides 360k of storage capacity.

The only requirement of the communications' software is to

insure that the communication variables stated previously for the UART are placed in a file on a compatible communications' software disk. The execution of this file in a computer system, equipped with MODEM capability, provides the operator of the automated cone penetrometer with a compatible system to communicate with the Tattletale data logger.

Physical linkage of the computer to the Tattletale is accomplished by using the RS-232, TC-4 communications cable, with the male end attached to the Tattletale data logger and the female end attached to the computer. Following this physical connection, the **Dump** mode is established as stated in the Operator's manual followed by the execution of the communication's file. The execution of this file will establish successful linkage of the computer to the Tattletale data logger. At this point the operator is able to retrieve the data in the data logger by following the steps outlined in the Operator's Manual or to edit the program as needed. The editing of the program can be accomplished either by use of the TTBASIC operating system, which is relatively the same as the BASIC language, or to use a special editing program.

3.5.2 Manipulation and Interpretation of Retrieved Data

Once the operator has successfully completed the procedures as outlined in the **Operator's Manual** for the retrieval of data, the data from the penetration tests are automatically stored on a

disk in the format as shown in Figure 3-8. The penetration tests are numbered and stored sequentially; therefore, tests will be listed from left to right with the test furthest to the left being the first penetration test and the test furthest to the right being the last penetration test. The format used to store the data allows the data to be easily imported into an electronic spreadsheet program for manipulation. LOTUS 1,2,3 was used in the conduct of this research to manipulate the data. The manipulation of the data by LOTUS will be discussed in general terms in the remainder of this section and is procedurally outlined in the **Operator's Manual** for additional reference.

Before any data is imported utilizing the LOTUS program, a blank, formatted spreadsheet file as shown in Figure 3-9 is constructed utilizing the LOTUS program. This file is retrieved at the initiation of the spreadsheet program and then the data file created during the **Dump** sequence is directly imported so that the columns in the data file line-up accordingly in the blank formatted spreadsheet file. This stage of data manipulation is depicted in Figure 3-10. The retrieved data file expresses the soil resistance (force) in pounds and the depth in positive inches. To facilitate the process of obtaining a cone index, an additional column is required in the spreadsheet to divide the pounds of force by the base area of the cone to obtain units in pounds per square inch (CI). In addition, another column is created enabling the depth of penetration to be multiplied by a negative one to accommodate plotting purposes.

Therefore, the initial portion of a completed spreadsheet, utilizing LOTUS, will resemble Figure 3-11. At this point the graph commands of LOTUS can be utilized to develop plots of Cone Index (psi) versus Depth (inches).

The beauty of utilizing LOTUS to manipulate the data, as presented in the above paragraphs, is that other, more powerful, graphing and charting software programs accommodate the LOTUS formatting of data to create graphs and charts. This capability provides the operator of the automated data acquisition device with the means of increasing the possibilities of comparing sets of penetration tests directly in one chart or graph. This added capability is evident in the graphs presented in Chapters 5 and 6 which were developed using the Microsoft Chart software.

FIGURE 3-8

OFFLOADED DATA FORMAT FROM TATTLETALE

AREA= 3:	TEST #= 4:		AREA= 3:	TEST #= 5:"	
CONE= 7:	MARK= 0:		CONE= 7:	MARK= 0:'	
DEPTH	LOAD	TIME	DEPTH	LOAD	TIME"
0.00	0.00	3.25	0.00	0.00	3.12
0.25	0.00	6.28	0.25	0.00	6.22
0.50	0.00	9.75	0.50	0.00	9.67
0.75	0.00	12.59	0.75	0.00	12.55
1.00	0.00	16.28	1.00	0.00	16.28
1.25	0.00	19.41	1.25	0.00	19.19
1.50	0.00	22.83	1.50	0.00	23.15
1.75	0.00	25.88	1.75	0.00	26.07
2.00	0.00	29.44	2.00	0.00	29.63
2.25	0.42	32.77	2.25	0.42	33.19
2.50	0.85	35.99	2.50	0.85	36.56
2.75	1.27	39.19	2.75	1.27	39.55
3.00	1.70	42.70	3.00	1.70	43.10
3.25	1.70	45.89	3.25	1.70	46.29
3.51	2.12	49.02	3.51	2.12	49.55
3.76	2.97	52.47	3.76	2.12	52.68
4.01	3.40	56.10	4.01	2.97	57.20
4.26	3.82	59.25	4.26	3.40	60.37
4.51	3.82	62.64	4.51	3.40	63.79
4.72	4.25	66.34	4.76	3.82	66.93
5.01	4.68	70.16	5.01	4.25	70.78
5.26	4.68	73.35	5.26	4.68	73.97
5.51	5.10	76.62	5.51	4.68	77.37
5.76	5.10	79.66	5.76	5.10	80.51
6.01	5.10	83.29	6.01	5.53	83.95
6.26	5.10	86.29	6.26	5.53	87.08
6.51	5.10	89.58	6.51	5.95	90.4[illegible]
6.76	5.10	92.64	6.76	5.95	93.60
7.02	5.53	96.23	7.02	5.95	97.21
7.27	5.53	99.46	7.27	5.95	100.44
7.52	5.95	103.09	7.52	5.53	103.94
7.77	6.80	106.28	7.77	5.95	107.17
8.02	7.23	109.82	8.02	5.95	110.76
8.27	8.08	112.97	8.27	5.53	113.66

FIGURE 3-9

```
*********************************************************
BLANK FORMATTED SPREADSHEET TO MANIPULATE
   DATA FROM CONE PENETRATION TESTING
*********************************************************
     AREA= 9:   TEST #= 5:
     CONE= 6:      MARK= 0:
---------------------------------------------------------
  DEPTH     LOAD      TIME          CI       DEPTH

 (INCHES)   (LBS)     (SEC)        (PSI)   (INCHES)
---------------------------------------------------------
  A 12      B 12               +B12/.5   +A12*-1
```

FIGURE 3-10

****

FORMATTED SPREADSHEET TO MANIPULATE DATA
FROM CONE PENETRATION TESTING

****

AREA= 9: TEST #= 5:
CONE= 6: MARK= 0:

DEPTH (INCHES)	LOAD (LBS)	TIME (SEC)	CI (PSI)	DEPTH (INCHES)
0	0	3.84		
0.25	0	7.38		
0.5	0	11.51		
0.75	0	15.03		
1	0	19.46		
1.25	0	23.17		
1.5	0.42	27.34		
1.75	0.85	30.97		
2	1.27	35.29		
2.25	1.7	39.24		
2.5	2.12	43.3		
2.75	2.12	46.98		
3	2.55	51.25		
3.25	2.97	55.25		
3.51	2.97	59.05		
3.76	3.4	64.06		
4.01	3.82	68.26		
4.26	4.25	72.32		
4.51	3.4	76.97		
4.76	5.1	79.99		
5.01	5.53	84.51		
5.26	5.53	88.31		
5.51	5.95	92.32		
5.76	5.95	96.12		
6.01	6.38	100.26		
6.26	6.8	104		
6.51	6.8	108.03		
6.76	6.8	111.79		
7.02	6.8	116.1		
7.27	7.23	119.88		
7.52	7.23	124.14		
7.77	7.65	127.94		
8.02	7.65	132.29		
8.27	7.65	136.07		

FIGURE 3-11

++

FORMATTED SPREADSHEET WITH MANIPULATED DATA
FROM CONE PENETRATION TESTING

++

AREA= 9: TEST #= 5:
CONE= 2: MARK= 0:

DEPTH (INCHES)	LOAD (LBS)	TIME (SEC)	CI (PSI)	DEPTH (INCHES)
0	0	3.84	0.00	0
0.25	0	7.38	0.00	-0.25
0.5	0	11.51	0.00	-0.5
0.75	0	15.03	0.00	-0.75
1	0	19.46	0.00	-1
1.25	0	23.17	0.00	-1.25
1.5	0.42	27.34	0.84	-1.5
1.75	0.85	30.97	1.70	-1.75
2	1.27	35.29	2.54	-2
2.25	1.7	39.24	3.40	-2.25
2.5	2.12	43.3	4.24	-2.5
2.75	2.12	46.98	4.24	-2.75
3	2.55	51.25	5.10	-3
3.25	2.97	55.25	5.94	-3.25
3.51	2.97	59.05	5.94	-3.51
3.76	3.4	64.06	6.80	-3.76
4.01	3.82	68.26	7.64	-4.01
4.26	4.25	72.32	8.50	-4.26
4.51	3.4	76.97	6.80	-4.51
4.76	5.1	79.99	10.20	-4.76
5.01	5.53	84.51	11.06	-5.01
5.26	5.53	88.31	11.06	-5.26
5.51	5.95	92.32	11.90	-5.51
5.76	5.95	96.12	11.90	-5.76
6.01	6.38	100.26	12.76	-6.01
6.26	6.8	104	13.60	-6.26
6.51	6.8	108.03	13.60	-6.51
6.76	6.8	111.79	13.60	-6.76
7.02	6.8	116.1	13.60	-7.02
7.27	7.23	119.88	14.46	-7.27
7.52	7.23	124.14	14.46	-7.52
7.77	7.65	127.94	15.30	-7.77
8.02	7.65	132.29	15.30	-8.02
8.27	7.65	136.07	15.30	-8.27

CHAPTER 4

LABORATORY VALIDATION AND VARIABLE TESTING PROGRAM

4.1 PURPOSE OF TESTING PROGRAM

The laboratory validation and variable testing program established for this study has as its focal point the need to verify the capability of the automated military cone penetrometer to provide reliable and repeatable results during penetration testing. Encompassed in this overall objective of the testing program is the need to insure that the operational concepts of the apparatus and the program in the data logger, as presented in Chapter 3, are satisfied. In addition, specific testing variables: rate of penetration, cone size, and concentrated surface load effects on cone resistance data; are roughly analyzed to identify possible modifications for the device and possible further research topics for analysis. In addition, the analysis of this program establishes observations on the sensitivity of the device and the effect of boundary conditions on penetration data.

The accomplishment of the validation/calibration testing phase in this program requires that the cone resistance data obtained with the automated military cone penetrometer be compared to the results from previous research efforts. In addition to a comparison of the various controlled parameters to

results obtained by researcher publishings in the readily available literature, this effort was vastly enhanced by data available from research conducted at Georgia Tech in the early 1960's. The resulting data from tests conducted by Alexsander B. Vesic' were available for the current project. The major reason for choosing this data as a comparison base is the geometric similarity between Vesic's cone penetrometer and the automated military cone penetrometer. In addition, Vesic's data was developed using a soil which is readily available to the researcher. Also, the conditions under which Vesic's testing program were developed are relatively easily modeled under laboratory conditions. The aspects of Vesic's work are discussed in more detail in the following section of this chapter.

Following a synopsis of Vesic's work, the testing program; to include soil properties, testing equipment and materials, test model preparation, and the testing sequence and procedures; will be presented. Chapter 5 will then present and analyze the results of the testing program in comparison to Vesic's work and to relatively recent studies of the variable effects on cone resistance data.

4.2 VESIC'S TESTS ON CHATTAHOOCHEE RIVER SAND

In the early 1960's, Alexsander B. Vesic' conducted a large scale testing program designed to analyze the "Bearing Capacity of Deep Foundations in Sand". These tests were conducted

specifically to observe the bearing capacity effects of different geometrical shapes of foundations on varying densities of a sand foundation base and to compare these observations to corresponding theoretical values. Chattahoochee River sand provided the foundation base material for these tests and it exhibited a grain distribution as shown in Figure 4-1 and physical properties as depicted in Table 4-1. In the conduct of these tests, one of Vesic's primary concerns dealt with the placement and the corresponding control of the dry density of this sand base.

In placing the sand, Vesic' utilized a raining device which consisted of a container with a perforated bottom. Sand test beds of desired densities and elevations were constructed by feeding the container by means of a conveyor belt hopper and simultaneously lifting the perforated bottom container to maintain a specific height above the sample. The theory around this concept of placing sand is that the density of the sand test bed being constructed is directly related to "the height of free fall of sand as long as other variables (rate of flow) remain the same" (Vesic', 1963). Figure 4-2 depicts the relationship between the density of sand and the height of fall as established by Vesic' in the conduct of these tests. These tests demonstrated that uniform test samples of loose and medium sand densities, where the relative density is less than 70, could be constructed following the procedures discussed above and utilizing the relationships established in Figure 4-2. However,

Table 4-1 Physical Properties of Chattahoochee River Sand
As Used by Vesic' (Domaschuk, 1965)

Specific Gravity	2.66
Maximum Void Ratio	1.10
Minimum Void Ratio	0.61
Coefficient of Uniformity	2.0

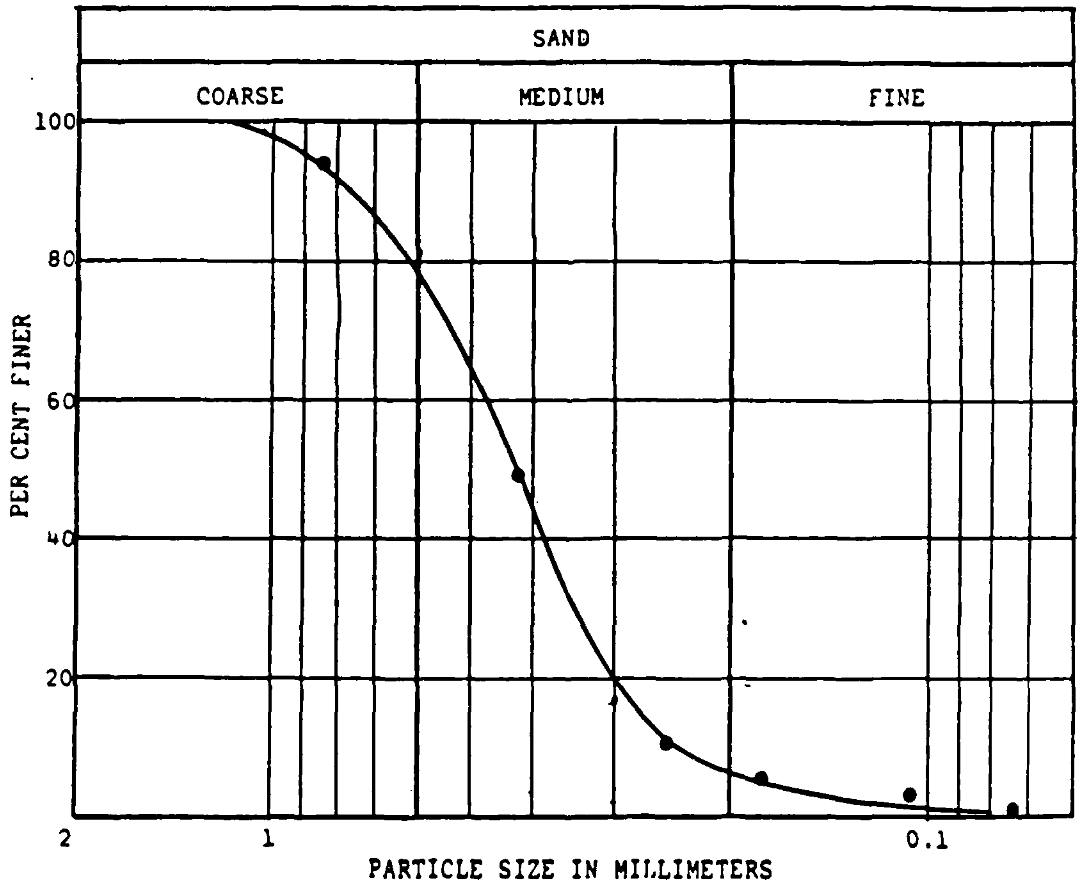


Figure 4-1 Grain-Size Distribution for Chattahoochee Sand.
As Used By Vesic' (Domaschuk, 1965)

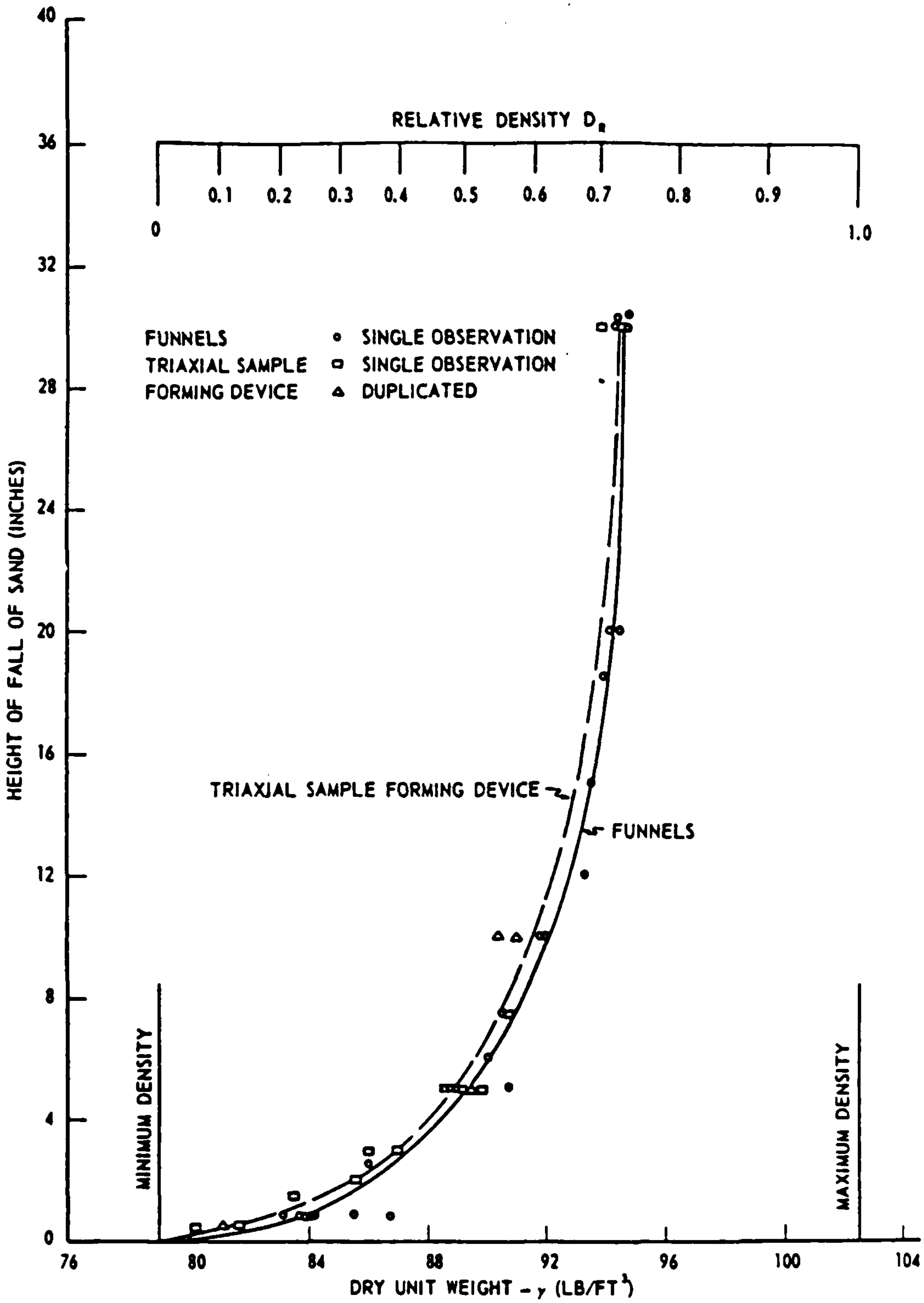


Figure 4-2 Relative Density of Sand as Function of Height of Fall. (From Vesic, 1963)

the construction of sand test samples with relative densities greater than 70 required that the sand be rained from a height of 30 inches through the perforated bottom container in 4 inch thick lifts. These lifts of sand were then subjected to surface vibrations to establish uniform dense samples.

The key variable in the bearing capacity tests conducted by Vesic' was the need to insure that the foundation sand base test models constructed were of uniform density. In order to establish the results as depicted in Figure 4-2 and to subsequently establish the density of the constructed test model sand bases, Vesic' utilized what he called "a simple static-cone micropenetrometer" to establish a correlation between dry density of sand and cone resistance. This device had a base cone diameter of .5 inches and a shaft casing diameter of 3/8 inches. The device measures a total resistance, combining both point bearing and skin resistances. The geometric and resistance measuring characteristics of this device are the same as those of the automated military cone penetrometer.

To establish the relationship between the cone resistance values and the corresponding sand density with depth, Vesic' conducted a separate laboratory testing series using the micropenetrometer. This test series utilized a 24 x 16 x 60 inch box which was placed upon a set of scales and then filled in the same manner as previously discussed for the construction of the sand foundation base. The known volume along with the corresponding weight as measured by the scales established the

unit weight of the material. The micropenetrometer was then pushed into the sand test bed by use of a screw jack at a rate of 4 inches per minute to establish the relationship between the sand's dry unit weight and cone resistance (cone index) as is depicted in Figure 4-3. This plot of cone resistance versus depth was then utilized by Vesic' to verify the uniformity and density of the sand foundation base test models.

Figure 4-3 provides data which demonstrates key aspects of the cone resistance relative to the sand's dry density and depth of penetration. In general, the cone resistance value increases with increasing penetration depth. Specifically, at any given dry sand density, the cone resistance appears to increase rapidly in the upper portion of the soil strata followed by a gradual increase with depth. Vesic's data, as presented in the figure, provides a clear picture of what the cone resistances at dry densities in the range of 83 to 97 pounds per cubic foot are expected to be to a depth of 50 inches. In addition, similar recent works by Baldi, et.al. (1981) have further confirmed that the relationship between cone resistance and relative density of a sand does qualitatively exist. Baldi's work established this relationship for medium-coarse overly consolidated and normally consolidated sands in both dry and saturated conditions.

A key question at this point concerns the absence of data for the anticipated cone resistance values with depth over the full range of relative densities for Vesic's Chattahoochee River sand. As depicted in Figure 4-2, the data covers a range of dry

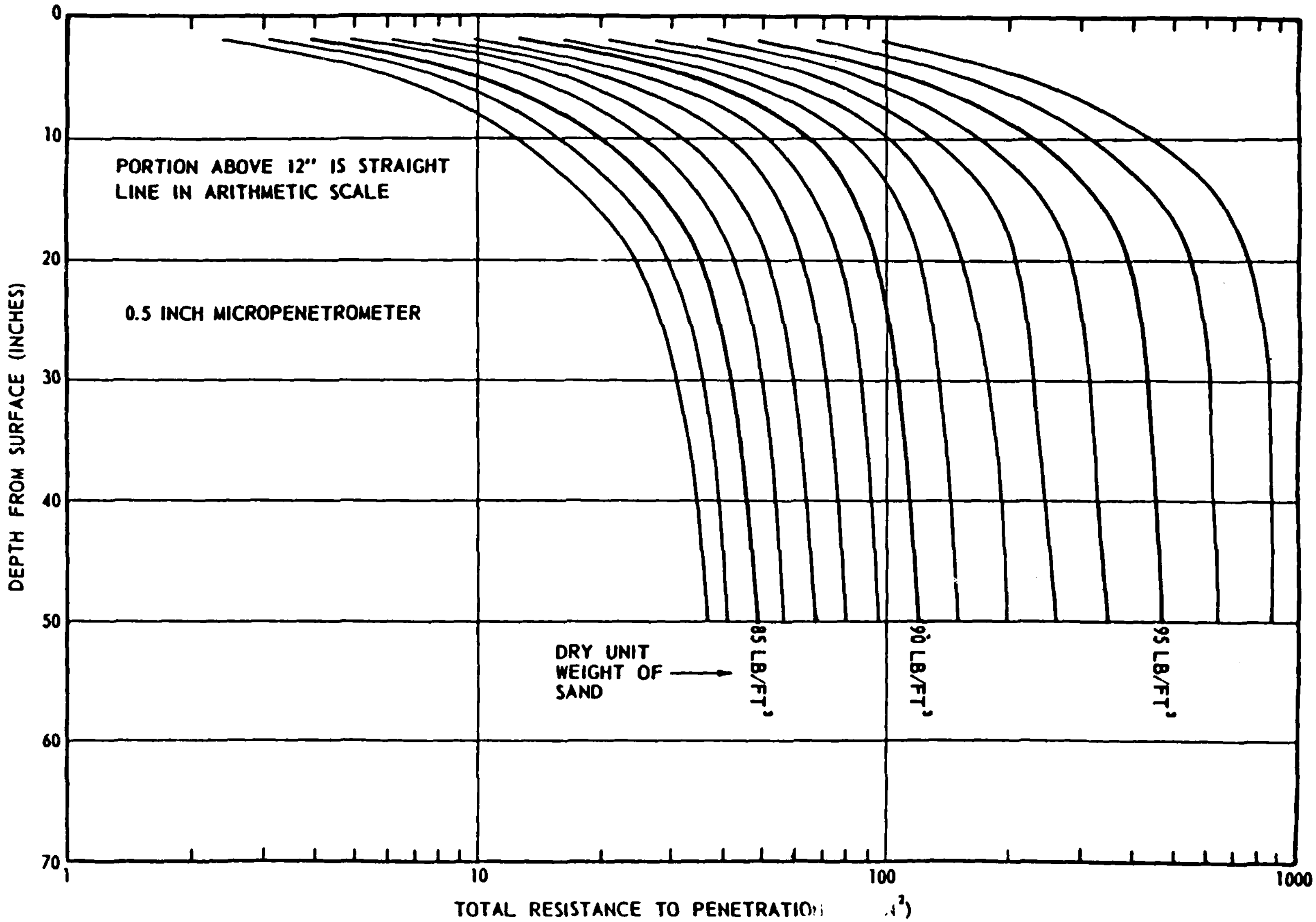


Figure 4-3 Relationship Between Depth and Total Penetration Resistance for Different Sand Densities.

(From Vesic, 1963)

densities from 83 to 97 pounds per cubic foot; however, as established in Table 4-1 and Figure 4-2, the minimum and maximum dry densities occur around 79 and 102.5 pounds per cubic foot, respectively. Therefore, the cone resistance values with depth must be interpolated for any value of dry density less than 83 and greater than 97 pounds per cubic foot. Because of the apparent consistency of all of the curves, presented by Vesic', this is not anticipated to be of great hardship. Unfortunately, the point that these plots of data are so smooth over the range of dry densities will prove to be a questionable trait in itself. This aspect will be further discussed in the section which compares Vesic's data to that observed with the automated military cone penetrometer.

4.3 THE VALIDATION AND VARIABLE TESTING PROGRAM

The testing program developed for the validation/calibration of the automated military cone penetrometer follows the basic concept established by Vesic' in the formulation of Figure 4-3. Specifically, the program establishes the means by which the cone resistance data obtained with the automated military cone penetrometer over various loose, medium, and dense dry densities of a Chattahoochee River sand can be compared to the data in Figure 4-3. Six series of tests, delineated by the dry density of the sample, were conducted with at least two series within each of the three general states of density. In total, this

testing program consisted of thirty individual tests spread among the six series. Each individual test is differentiated from another based on the testing sample's dry density and the change in the testing variables. As stated in the introduction to this chapter, the testing variables which were roughly analyzed are the rate of penetration, cone size, and confining pressure. The boundary effect and the sensitivity of the device were indirectly scrutinized within the sequence of each of these variable tests. The boundary effects concern the location of a particular penetration within the testing chamber. The sensitivity of the device concerns the precision to which the computer program in the data logger and the automated system as a whole can effectively distinguish data over varying conditions.

Throughout the validation and variable testing program the physical properties of the test sand, the equipment used, and the procedures followed in sample preparation and penetration testing are nearly identical to that of Vesic'. The following sub-sections will present the particular equipment, materials, and procedural sequence parameters utilized in the conduct of this testing program. Variances in any of these parameters to that used by Vesic' will be noted. Following the discussion of these parameters, the analysis of the results will be presented in Chapter 5.

4.3.1 The Cone Penetrometer

The automated military cone penetrometer, as presented in Chapter 3, is the basic instrument used in the conduct of this testing program. This basic system consists of all the components of the automated data acquisition system, a .5 inch diameter 30 degree cone (.2 square inch base area), and a 3/8 inch steel shaft. The data acquisition system measures total resistance (Base + Skin) and depth, storing average data every .25 inches over a two foot depth. The geometric configuration of the cone and rod is nearly identical to that utilized by Vesic' in the conduct of his tests.

The only substantial variance in the penetrometer of this program to that of Vesic's occurs in the depth of penetration and the automated data acquisition capabilities. The variance in the depth of penetration is based on the fact that the automated military cone penetrometer is set-up to measure over a critical depth of 24 inches, whereas Vesic's test data is established to a depth of 50 inches. This variance should have no affect upon the results and conclusions which are to be presented in the analysis section. An additional variance to Vesic' tests involves the use of the .5 square inch 30 degree cone in the current efforts to provide analyses on the effect of cone size on soil resistance.

4.3.2 The Sand's Physical Properties

The sand utilized in the conduct of this testing program was taken from the Chattahoochee River and is considered to be very similar to that used by Vesic'. The physical properties and the grain-size distribution of this Chattahoochee River sand are presented in Table 4-2 and Figure 4-4, respectively. In addition, the data pertaining to the physical properties of the sand utilized by Vesic' had been incorporated into Table 4.2 to facilitate the comparison of properties.

From the data in both Table 4-2 and Figure 4-4 it is obvious that the sands from the two separate tests are very similar. The largest variance seems to be in the determination of the minimum void ratio and the maximum dry density. This variance did not seem to affect the results which will follow in the analysis section; therefore, the difference can possibly be attributed to the procedural technique utilized in determining these properties and the equipment available to the user.

TABLE 4-2 PHYSICAL PROPERTIES OF THE CHATTAHOOCHEE RIVER SAND

PROPERTIES	CURRENT TESTING PROGRAM	VESIC' TESTING
SPECIFIC GRAVITY	2.66	2.66
MAXIMUM VOID RATIO	1.13	1.10
MINIMUM VOID RATIO	.71	.615
MAXIMUM DRY DENSITY	97.12 pcf	102.5 pcf
MINIMUM DRY DENSITY	78.11 pcf	79.0 pcf

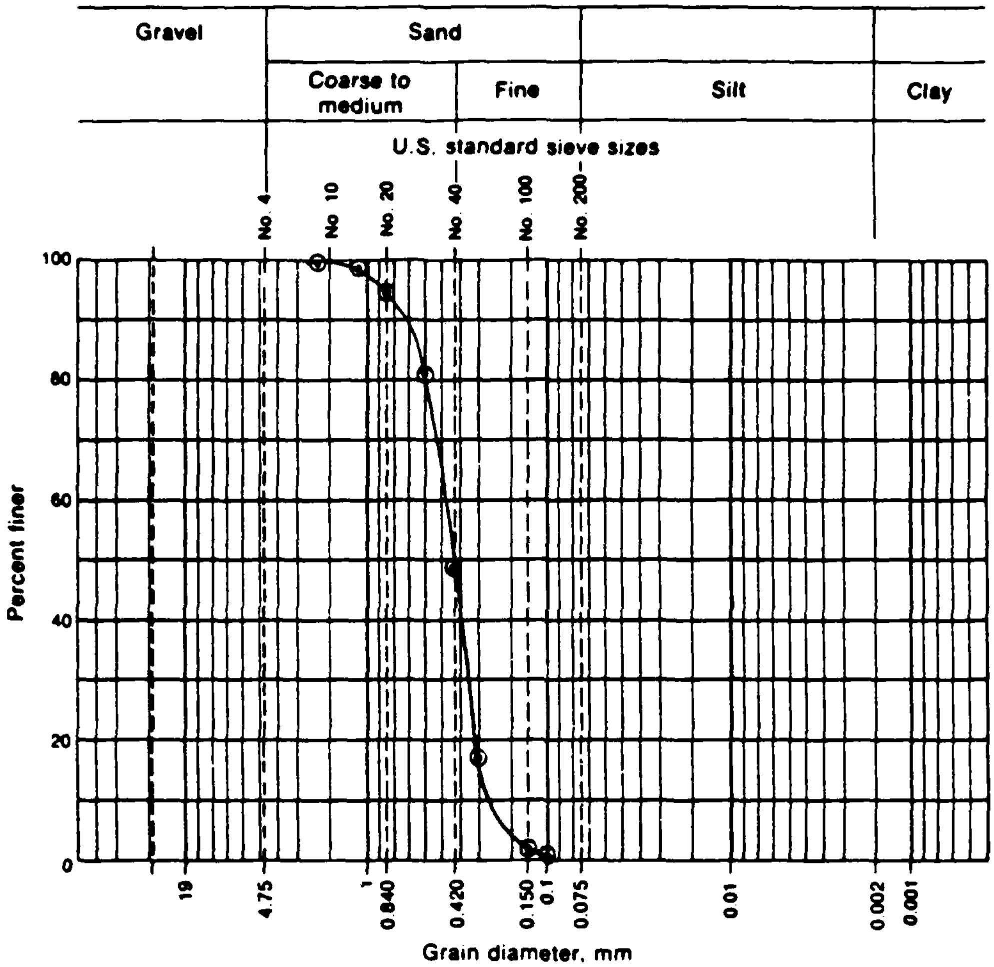


FIGURE 4-4 Grain-Size Distribution for Chattahoochee River Sand Used in the Laboratory Testing Program

4.3.3 The Testing Chamber

A circular drum with a diameter of 22.25 inches and a height of 34 inches was used as the testing chamber in this exercise. As stated previously, Vesic' utilized a box with the following dimensions: 24 x 16 x 60 inches. It is obvious from these dimensions that the testing chamber's utilized in these two testing programs are not identical; however, when comparison of the diameter ratio's for the two testing programs is made, the variance in dimensions are not considered to adversely affect the capability of the researcher to compare testing data. In addition, it will be demonstrated that the facility utilized in the present study is superior to that used by Vesic'.

The diameter ratio is calculated by dividing the diameter of a circular testing chamber by the diameter of the cone being used in a penetration. In the rectangular chamber used by Vesic', a critical diameter ratio is determined by dividing the smallest horizontal dimension of the rectangular box by the diameter of the cone being used in a penetration. Such a calculation demonstrates that in actuality the diameter ratio is providing an insight to the effect boundary conditions and adjacent cone penetrations have upon a particular cone penetration. The rigidity of the boundary, the smoothness of the boundary, and the proximity of the boundary to the penetrating cone play a key role in the data one would expect to obtain. This is particularly true for granular soils in the dense state

where a larger diameter ratio is considered to provide a more realistic view of real world boundary conditions.(Parkin and Holden, 1980) For a more detailed discussion on this topic of diameter ratios and the effect of boundary conditions on penetration testing, one is referred to Parkin and Holden (1980).

Assuming that both of the given containers are rigid and fairly rough sided, the critical diameter ratios are as follows: Vesic's testing program had a 32; the current testing program has 44.5 for the .2 square inch cone and 27.89 for the .5 square inch cone. Remember, the .2 square inch cone is the basis by which data will be compared to Vesic' and the .5 square inch cone is a variable in the current testing program.

4.3.4 Sample Preparation and Dry Density Determination

Specific support equipment is required for sample preparation. Samples are formed using sand raining methods established by Vesic' and as described by Marcuson and Bieganousky (1976). The equipment consists of a sand reservoir/dispenser and a raining device hopper with perforations in the bottom formed by a series of screens. This equipment is pictured in Figures 4-5 and 4-6. The sand reservoir/dispenser is a circular drum of the same dimensions as the testing chamber and with modifications to allow the dispensing of sand from the bottom of the reservoir. This modification consists of a welded pipe assembly with a sliding valve which allows the flow of sand

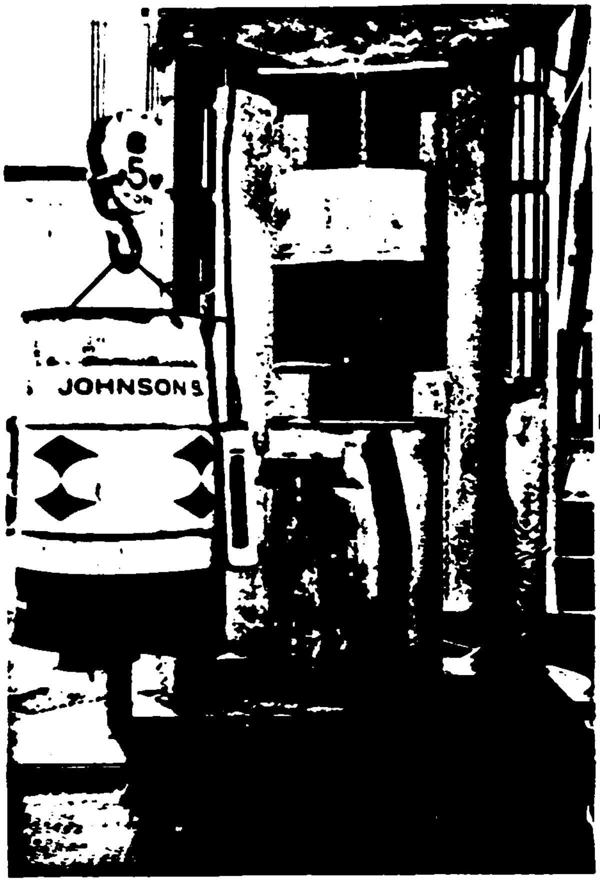


FIGURE 4-5

SUPPORT EQUIPMENT: SAND RESERVOIR, RAINING DEVICE, AND TESTING CHAMBER

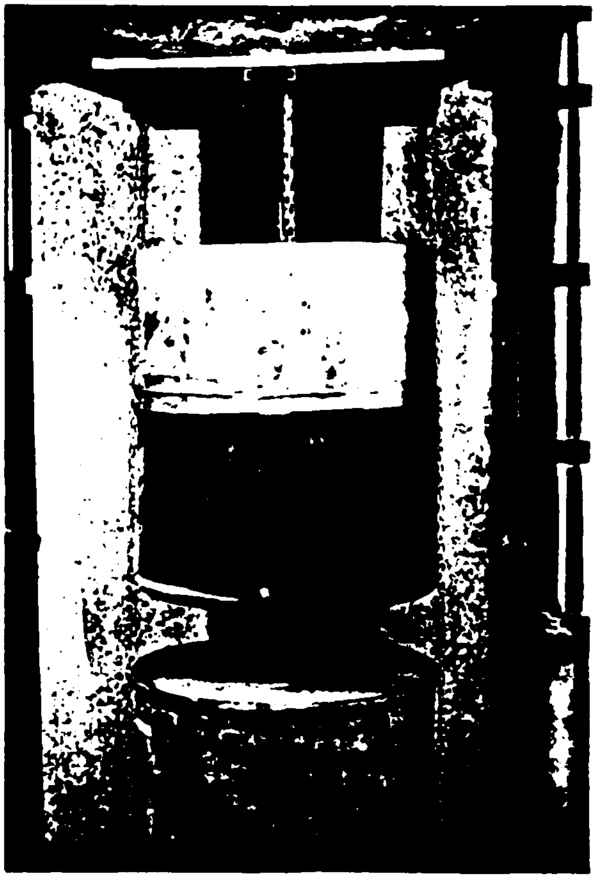


FIGURE 4-6

RAINING DEVICE HOPPER ATTACHED TO SECURING FRAME ABOVE TESTING CHAMBER

to be started and stopped through the attached three inch flexible hose. The hopper provides the support for the series of screens located at the bottom of the metal portion of the hopper and is approximately 22 inches in diameter thus allowing it to fit inside the testing chamber. A rubberized guide sleeve is attached to the hopper and extends 30 inches from the screens to facilitate the raining sequence in the formation of medium density samples.

Loose density sand samples are formed by raising the sand reservoir above the testing chamber, opening the flow control valve, and raining the sand from an effective height of zero through the flexible hose into the testing chamber. This method produces repeatable loose density states of moderate uniformity.

Medium density preparation is accomplished by raising the sand reservoir above the testing chamber, opening the valve to allow the flow of sand through the flexible hose, and dropping the sand into the hopper and through the screen system into the testing chamber. Sample densities and uniformity are controlled by the height of fall of the sand and the opening size within the screen system. Since the opening size is constant, the height of the screen system above the top of the sample must be maintained throughout the raining process to establish consistent and uniform medium dense samples. For the equipment specifically noted in this program, the raining process exhibits a critical height above which there is negligible increase in the density of a sample. The maximum dry density achievable with this technique

approximately 88 pcf and is attainable at a critical height of 24 inches. The height of the screens above the sample is maintained by attaching the hopper to the ram of the loading frame as shown in Figure 4.5 and lifting the hopper as sand is dropped through the screens. Once the metal portion of the hopper has cleared the top of the testing chamber, the rubberized extension on the hopper acts as a guide for the raining sand.

As stated above, the equipment utilized in the raining process only achieves a maximum dry density in the medium dense state. Therefore, to form testing samples in the dense state requires that modifications to this process be implemented. Dense samples are formed by raining the sand into the testing chamber from a height of 24 to 30 inches in 6 inch lifts. Then each lift is tamped with a 10 pound weight from a height of 8 inches for 10 repetitions. Initially, it was surmised that this technique would possibly build in unwanted horizontal stress effects which would cause data comparison with that of Vesic' to be unacceptable; however, as will be presented in the analysis section, the results do not appear to be overly affected. Undoubtedly some over consolidation affects that are beyond the scope of the present study.

The key factor in the similarity between this testing program's sample preparation and that of Vesic' occurs in the determination of the sample's dry density. This testing program utilized a set of scales as shown in Figure 4-7 to establish the quantity of sand which had been placed in the testing chamber of

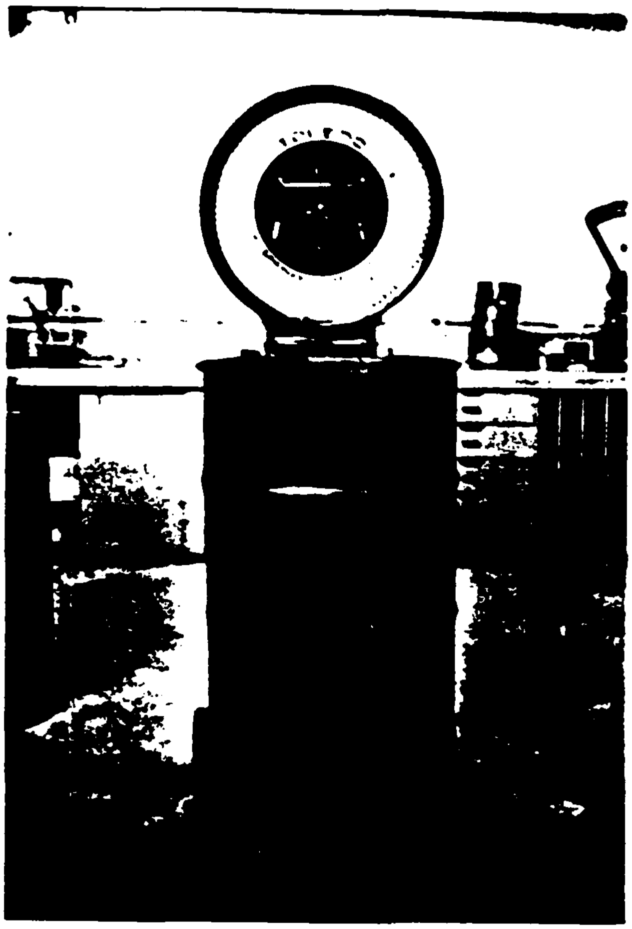


FIGURE 4-7

SCALES FOR DETERMINING WEIGHT OF SAND

known volume. This technique allows the determination of a particular sand sample's average dry unit weight which is used in comparing results to that of Vesic'. As stated in section 4.2, the use of scales to determine the weight of sand placed in a known volume is the same process used by Vesic'.

4.3.5 The Testing Sequence and Procedures

The testing procedure for a given dry density of sand is conducted in three stages: (1) sample preparation and density determination, (2) penetration of the sample with the automated cone penetrometer, and (3) downloading of the penetration data from the Tattletale data logger and analysis of the reduced data. The following paragraphs will list and discuss the steps associated with each of these stages.

The first stage consists of forming a sample of known density in the testing chamber. This is accomplished by following these steps:

(a) Attach the manufactured 'Cone Penetrometer Securing Frame" to the ram of the loading frame. The securing frame provides the means by which the raining device hopper is attached to the ram (see Figure 4-6) and by which the automated cone penetrometer is secured during test penetration. Figure 4-8 provides a picture of the securing frame while Figure 4-9 shows the frame attached to the ram and securing the automated military cone penetrometer.

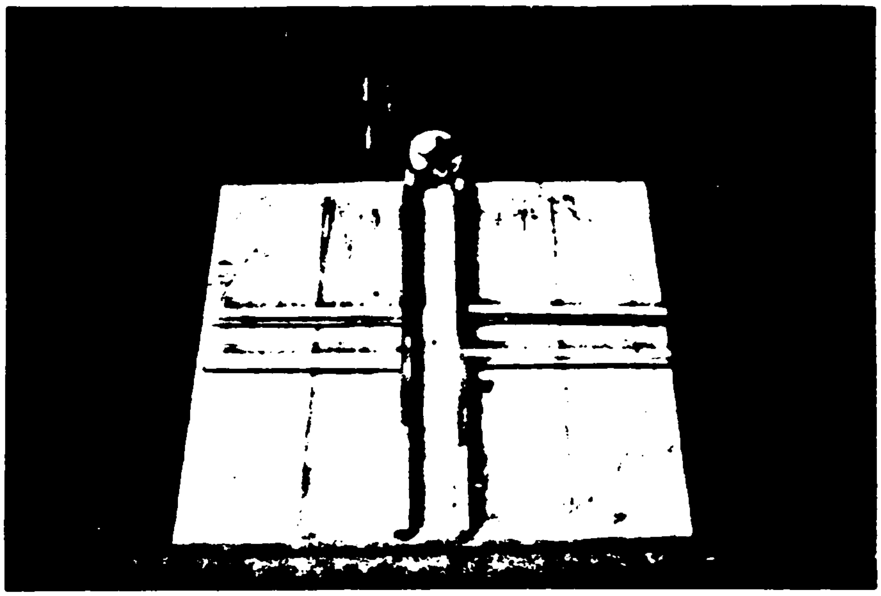


FIGURE 4-8

SECUR'NG FRAME WITH INSTRUMENTED BOXES

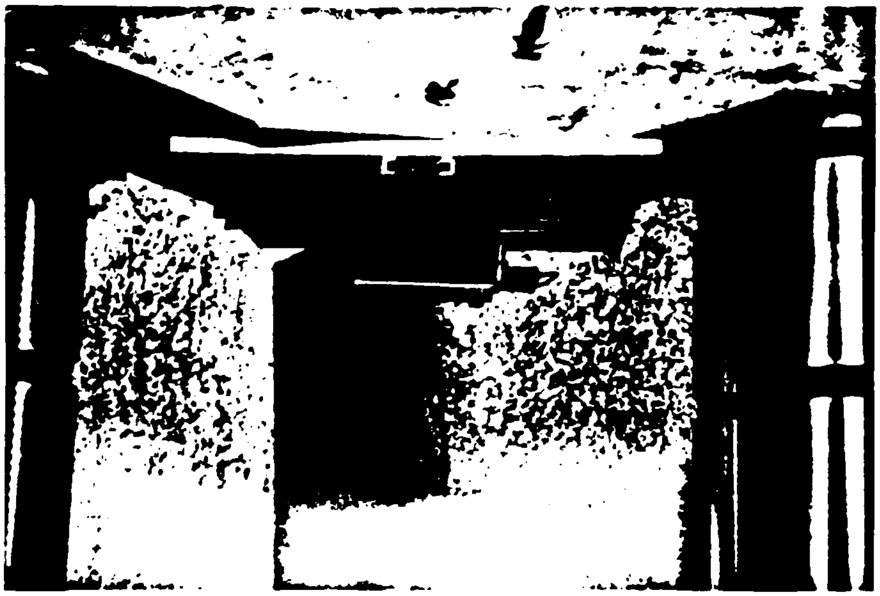
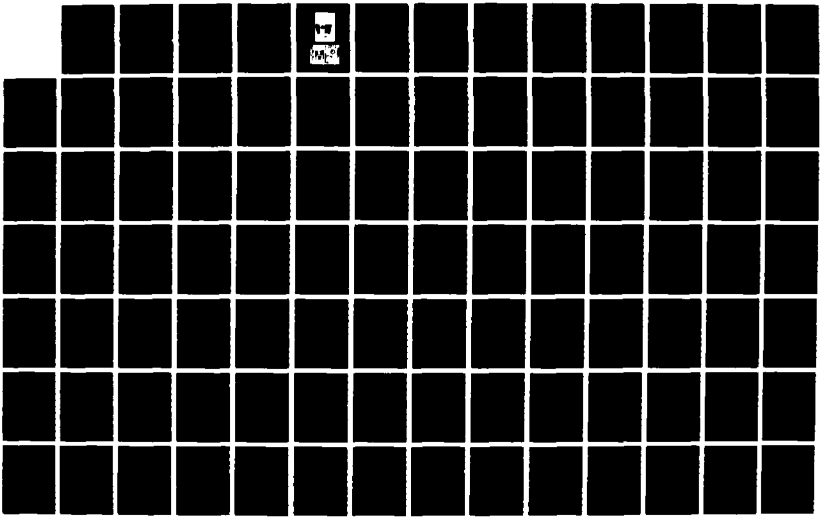


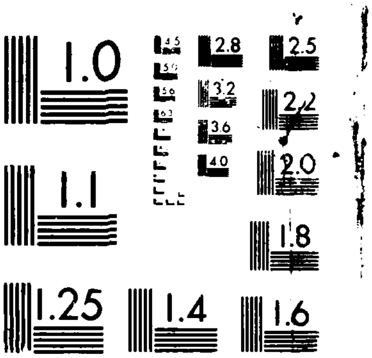
FIGURE 4-9

SECURING FRAME ATTACHED TO LOADING MACHINE

AD-A194 841 DEVELOPMENT AND INITIAL TESTING OF THE AUTOMATED MILITARY CONE PENETROMETER(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS GEOTE.. W E PERKINS

UNCLASSIFIED MAR 88 WES/MP/GL-88-5 F/G 8/10 NL




1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

(b) Center the testing chamber on the base of the loading frame.

(c) Determine the weight of the sand in the reservoir.

(d) Select the density (loose, medium, or dense) of sand desired and prepare the sample in accordance with section 4.3.4. In general this entails that loose samples be rained from an effective height of zero directly from the flexible hose. The medium and dense samples require that the raining device be attached to the ram of the loading frame and that the sand be dropped into the hopper while maintaining a critical height of at least 24 inches. Dense samples then require tamping with a 10 pound weight in 6 inch lifts. The samples are constructed to a height of one inch below the top of the testing chamber.

(e) Remove the raining device and carefully level the top of the sample by hand to establish a smooth testing surface. It is important that the testing chamber not be jarred or disturbed by any action other than the penetrating cone throughout the remainder of these procedures. Sample disturbance will cause a change in the sample's density and, thus, possibly affect the final results.

(f) Determine the weight of the sand remaining in the reservoir and subtract this quantity from the weight determined in step (c) to establish the weight and dry unit weight of the sample.

(g) Establish locations for cone penetrations as discussed in section 4.3.3 for the particular cone and sand density. The key factor in this step is to maximize the number of cone penetrations conducted in a given testing sample with minimum influence of test results measured by subsequent penetrations. Cone penetrations are separated from the testing chamber sides and other penetrations by a minimum of five inches for the loose and medium density samples while a minimum separation of eight inches is specified for the dense samples. These separation values were established during the course of this study and found to provide reliable data in comparison to the results as established by Vesic'.

Once the sample is formed and the penetration locations established and marked, the penetration of the sample with the automated cone penetrometer is conducted in accordance with the following steps:

(a) Attach the automated military cone penetrometer's control and loading boxes to the ram of the loading frame by sliding the handle into the guide wells of the securing frame as shown in Figure 4-9.

(b) Attach the shaft, foot rest, washer, and cone to the loading box as described in Chapter 3 and in the Operator's Manual. Attach the potentiometer string to the foot rest. Align the

components so that cone penetration is made at the specified locations. Five pound weights are gently placed on each side of the foot rest to secure this component and establish the datum for the potentiometer. Figure 4-10 shows the assembled cone testing apparatus and support equipment ready for a test advance.

(c) Follow the steps in the Operator's Manual to set-up the automated military cone penetrometer for the process of gathering penetration data.

(d) Establish the rate of penetration by setting the loading frame controls to a previously determined rate. This step requires that the given loading frame be previously calibrated to determine the necessary settings needed to establish the 4, 6, and 8 inches per minute rates used in this testing program. The rate of 4 inches per minute is the same as that used by Vesic' while the 6 and 8 inches per minute rates are additional variables established for this particular testing program.

(e) Conduct the cone penetration by placing the loading frame controls in the load position. During the penetration, automatic cone resistance and depth of penetration data are stored in the Tattletale data logger. Figure 4-11 shows the loading frame, prepared sample, and automated military cone penetrometer in place prior to the conduct of a test advance.

Once all of the locations in the prepared testing sample

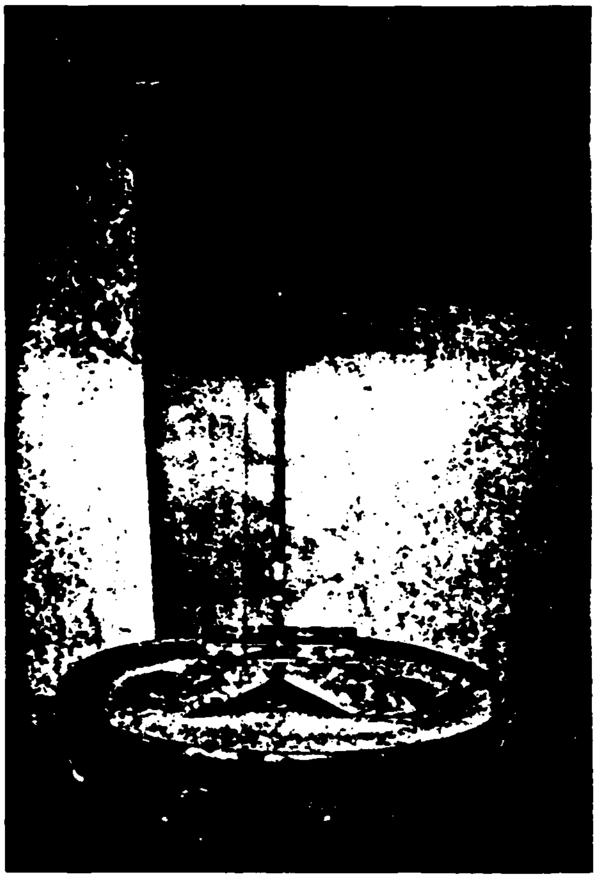


FIGURE 4-10
ASSEMBLED TESTING EQUIPMENT READY FOR TEST ADVANCE

FIGURE 4-11
LOADING FRAME, PREPARED SAMPLE, AND PENETROMETER PRIOR TO TEST

have been penetrated, the collected data is ready to be downloaded from the Tattletale data logger. The steps in this stage are presented in the Operator's Manual and Chapter 3 and will not be repeated in this section. However, the aspect of how many tests can be gathered and retrieved from the data logger at any given time needs further discussion at this point. This testing program utilizes the LOTUS electronic spreadsheet program to analyze the raw data retrieved from the data logger. The use of the LOTUS program requires that data files be imported into spreadsheet format. The data files of the automated military cone penetrometer are configured such that the maximum number of tests which can be imported into a spreadsheet is limited to five. Therefore, testing sessions with greater than five penetrations require that the single data file created in the downloading/retrieving of data stage be divided into several smaller files with a limiting size of five tests per file. This step allows each of the newly created files to be successfully imported to the LOTUS spreadsheet. To accomplish this additional step, an editing file program is required. This testing program utilized an editing program called "Brief Editor" to accomplish this data file dividing step once the data had been transferred to a floppy disk.

Once the spreadsheet files have been created, the test data is ready to be analyzed. The spreadsheets established in the above testing stage provide the means by which plots of cone resistance/index versus depth of penetration data can be

constructed, by either using the graphic's capability of the LOTUS program or of other graphics software which allow the data from LOTUS spreadsheets to be imported (such as MICROSOFT CHART). Utilizing the capabilities of the MICROSOFT CHART software, plots of the cone index versus depth of penetration are constructed to provide the means by which the analysis of this testing program is presented in the following chapter.

CHAPTER 5

LABORATORY TESTING RESULTS AND ANALYSIS

5.1 INTRODUCTION

As presented in Chapter 4, the validation and variabl testing program consists of various individual tests conducted within six different testing series. The differentiating factor between series are the testing sample densities while the tests within a given series are differentiated by the change in variables. Each of the individual tests within a given test series for the testing program is numbered (using sequential numbering for a given date) and summarized in Table 5-1. Each of the series of tests in the table are separated by a double line which indicates that a new testing sample was constructed with a different density. The table lists the series of test in the order of loose, medium, and dense states, respectively. Changes in the variables of cone size, rate of penetration, and concentrated surface loads (total pounds applied to each side of the foot rest) are specifically presented for each individual test. In addition, the remarks column indicates the location of penetration and in some cases states that the data for a particular test was lost. The reason for the lost data in tests 5-19 and 5-21 is based on the fact that the data was not properly set-up and transferred to the LOTUS computer program by the

TABLE 5-1 SUMMARY OF VALIDATION TESTS

LOOSE STATE

TEST #	DENSITY,pcf	CONE SIZE,IN	RATE	CONFINEMENT	REMARKS
1-19	82.7	.2	4in/min	5 POUNDS	CENTER
2-19	"	"	6in/min	"	FRONT CENTER
3-19	"	"	8in/min	"	BACK CENTER
4-19	"	"	4in/min	"	RIGHT CENTER
5-19	"	"	"	65 POUNDS	DATA LOST
11-29	80.8	.2	"	5 POUNDS	RIGHT CENTER
12-29	"	.5	"	"	LEFT CENTER
13-29	"	"	-----	65 POUNDS	BACK CENTER
14-29	"	.2	"	"	FRONT CENTER
15-29	"	"	"	110 POUNDS	LEFT-BACK
16-29	"	.5	-----	"	RIGHT-FRONT

MEDIUM STATE

TEST #	DENSITY,pcf	CONE SIZE,IN	RATE	CONFINEMENT	REMARKS
1-01	87.9	.2	4in/min	5 POUNDS	LEFT CENTER
2-01	"	"	8in/min	"	RIGHT CENTER
3-01	"	"	4in/min	"	BACK CENTER
4-01	"	"	"	"	FRONT CENTER
1-21	86.1	.5	4in/min	5 POUNDS	CENTER
2-21	"	.2	"	"	RIGHT CENTER
3-21	"	"	"	"	LEFT CENTER
4-21	"	.5	"	"	BACK CENTER
5-21	"	.2	"	65 POUNDS	DATA LOST

TABLE 5-1 SUMMARY OF VALIDATION TESTS CONTINUED

DENSE STATE

TEST #	DENSITY,pcf	CONE SIZE,IN	RATE	CONFINEMENT	REMARKS
1-29	96.4	.2	4in/min	5 POUNDS	RIGHT CENTER
2-29	"	"	"	"	LEFT CENTER
3-29	"	"	"	"	BACK CENTER
4-29	"	"	"	"	FRONT CENTER
5-29	"	"	-----	110 POUNDS	CENTER
6-29	95.9	.2	4in/min	5 POUNDS	LEFT CENTER
7-29	"	"	8in/min	"	RIGHT CENTER
8-29	"	.5	4in/min	"	BACK CENTER
9-29	"	"	8in/min	"	FRONT CENTER
10-29	"	.2	-----	110 POUNDS	CENTER

researcher; it is not related to a fault of the automated system as presented in Chapter 3 or the "Operator's Manual", but demonstrates that attention to test detail is important.

In presenting the results for analysis, two basic types of data plots are used. First, the data for a given series is presented in a semi-log plot of cone index versus depth which provides comparison capability to the data presented by Vesic' in Figure 4-3. Secondly, the data is presented in an arithmetic plot of cone index versus depth which provides detailed comparison between individual tests utilizing the changing variables. Plots of any results not presented in this chapter are located in Appendix B for further reference. The following sections will discuss the results obtained during this testing program. Initially, the results from all of the different density samples will be compared to Vesic's data. The analysis will then concentrate on each of the test variables: rate of penetration, cone size, and concentrated surface load effects, by presenting and discussing the results as they relate to the changes in these variables and to published studies which deal with these variables. The concluding section will roughly compare the results obtained in this testing program to the soil resistance values obtained using the WES Analytical Model developed by Baladi and Rohani (1981).

5.2 COMPARISON TO VESIC'S DATA

The data from this testing program is in excellent agreement with the results established by Vesic' in Figure 4-3. Figures 5-1, 5-2, and 5-3 for loose; Figures 5-4 and 5-5 for medium; and Figures 5-6 and 5-7 for dense samples present the results of the data obtained in the validation testing program. The corresponding data from Vesic's work for a given dry density is superimposed on these plots to establish the means by which comparison analyses of the data is accomplished. From these plots it is concluded that the automated military cone penetrometer provides penetration data which is almost identical to that established by Vesic' for a given dry density of Chattahoochee River sand. In addition, it is concluded that the data acquisition system explained in Chapter 3 works properly and can thus be utilized to perform additional analyses based on the accredited work performed by Vesic' and others.

5.2.1 Smoothness of Fit

In general, these figures demonstrate that cone resistance increases with depth and that the magnitude of increase is greater in the initial part of a sounding while tending to level off at a critical depth. This representation is in full agreement with that of Vesic'. However, there does appear to be a fine point discrepancy in the test data from these two tests.

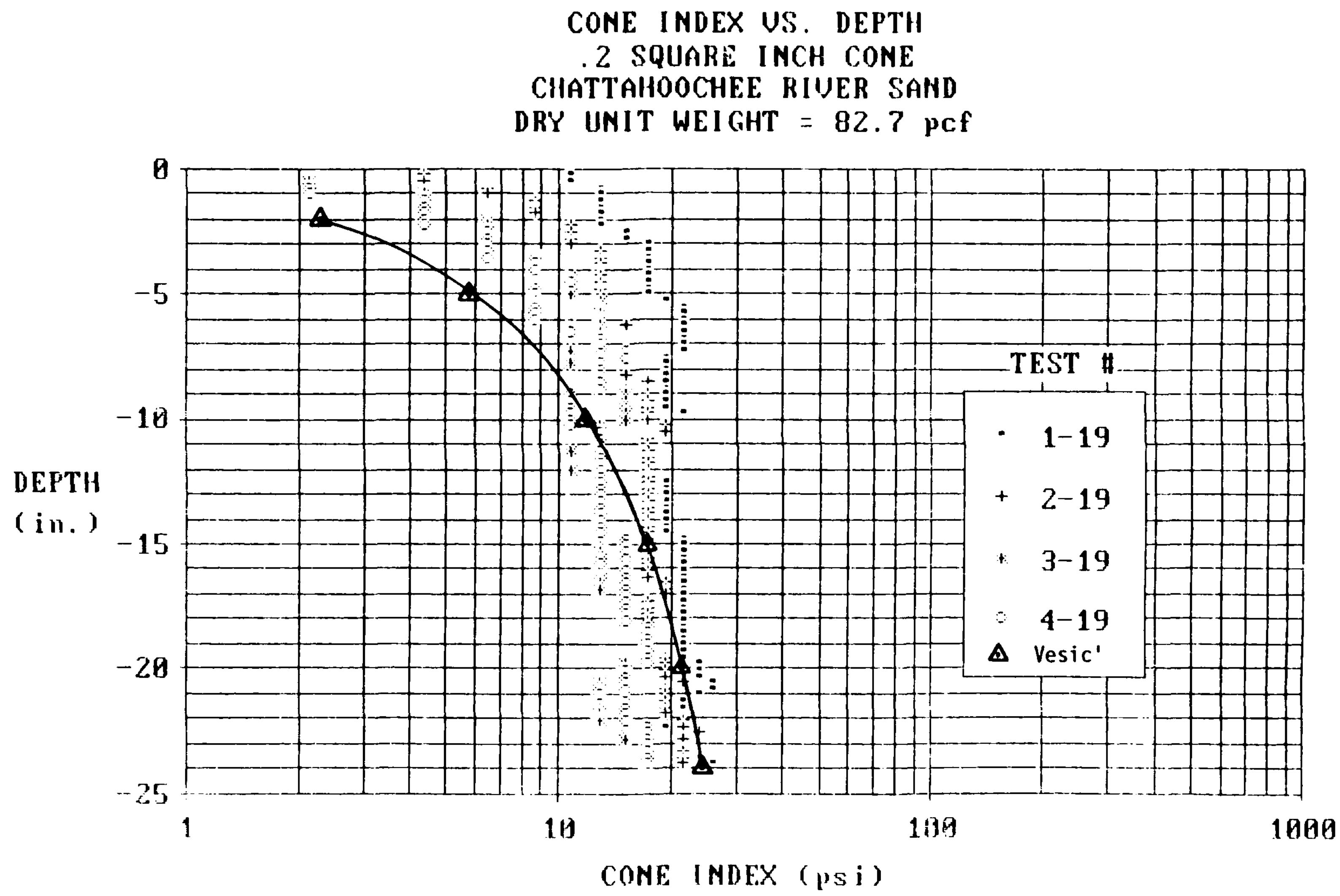

CONE INDEX VS. DEPTH
.2 SQUARE INCH CONE
CHATTAHOOCHEE RIVER SAND
DRY UNIT WEIGHT = 82.7 pcf
DEPTH (in.)
0
-5
-10
-15
-20
-25
1
10
100
1000
CONE INDEX (psi)
TEST #
1-19
2-19
3-19
4-19
Vesic'

FIGURE 5-1

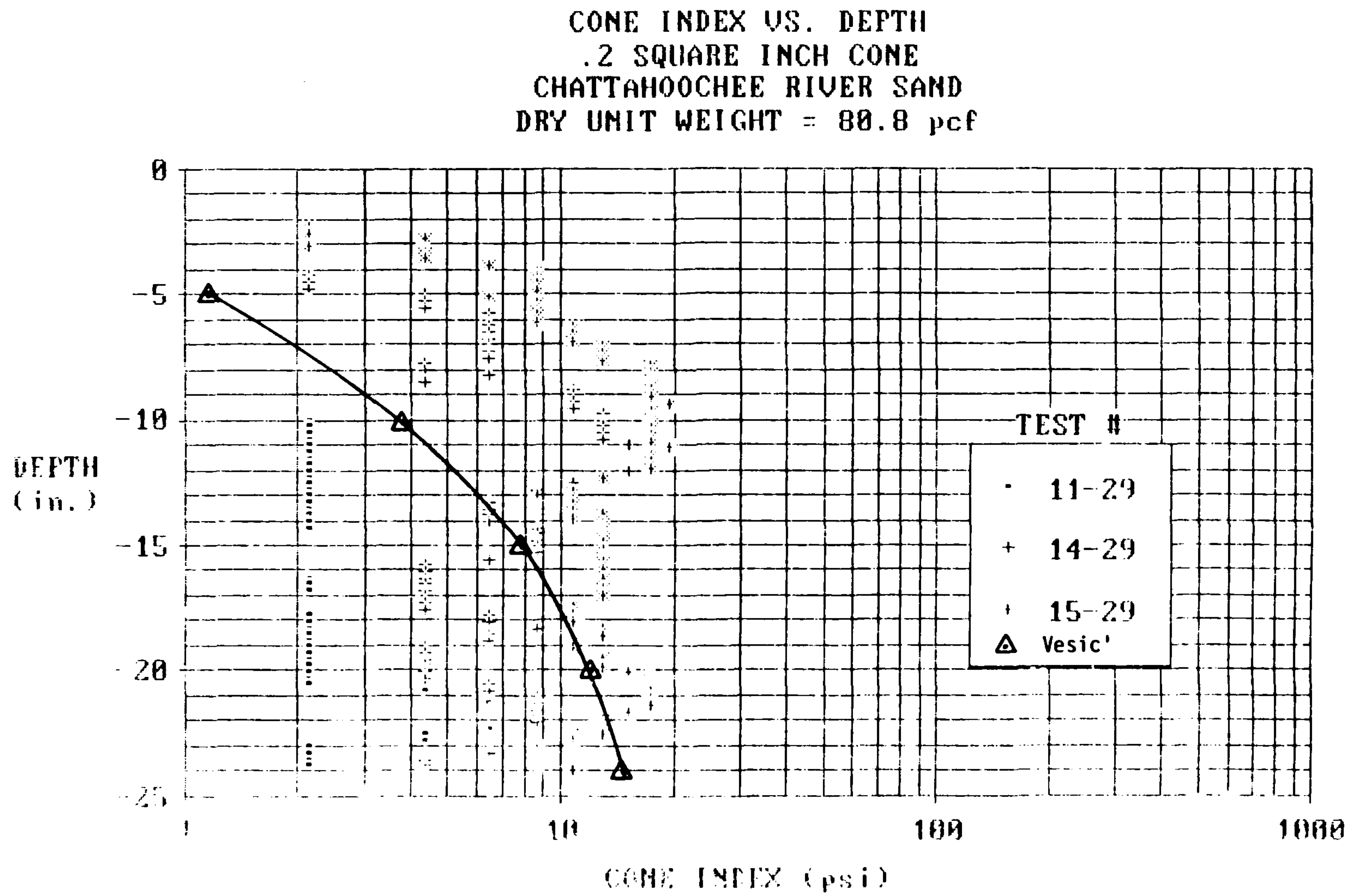

CONE INDEX VS. DEPTH
.2 SQUARE INCH CONE
CHATTAHOOCHEE RIVER SAND
DRY UNIT WEIGHT = 80.8 pcf
DEPTH (in.)
0
-5
-10
-15
-20
-25
1
10
100
1000
CONE INDEX (psi)
TEST #
11-29
14-29
15-29
Vesic'

FIGURE 5-2

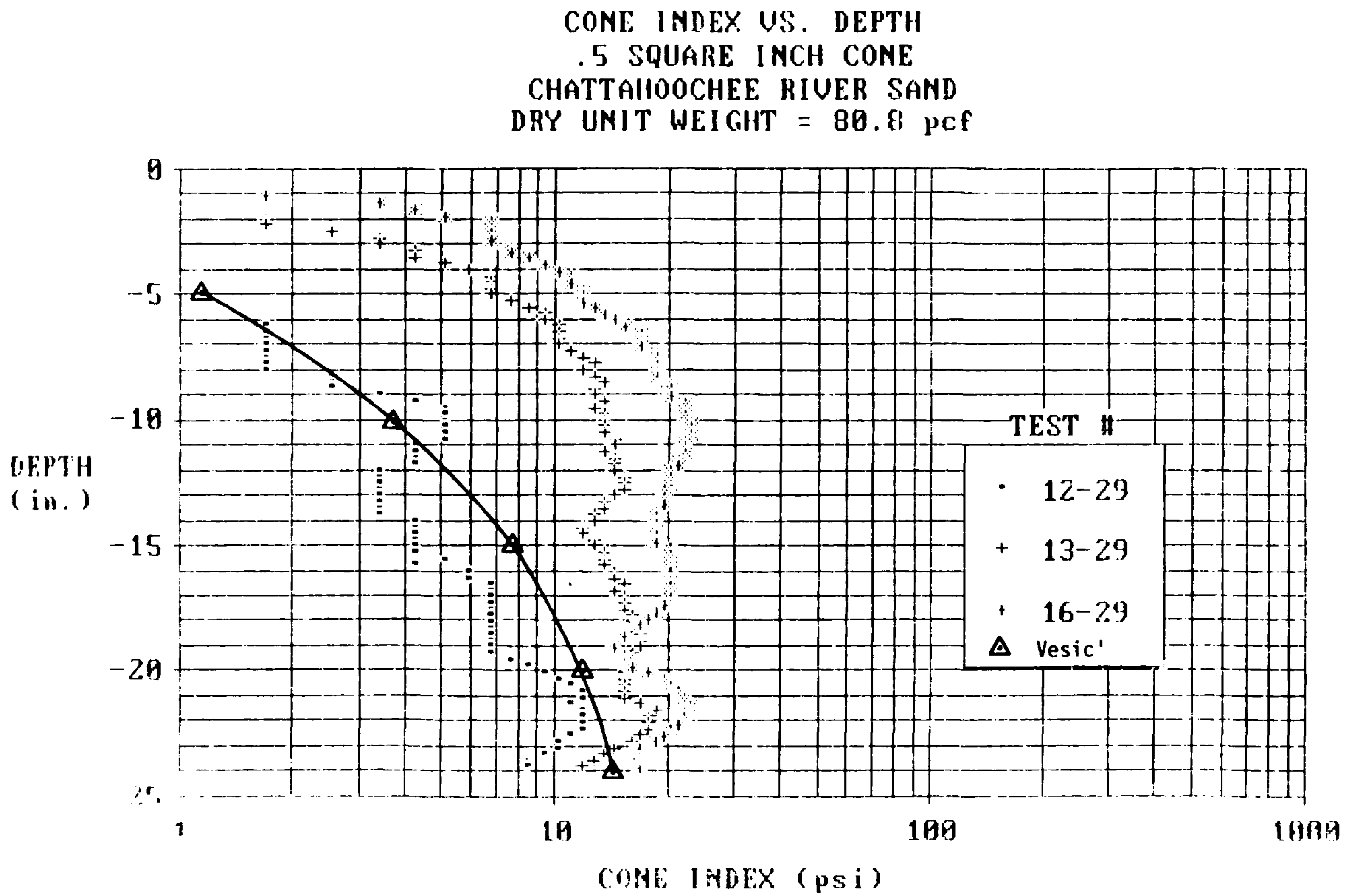

CONE INDEX VS. DEPTH
.5 SQUARE INCH CONE
CHATTAHOOCHEE RIVER SAND
DRY UNIT WEIGHT = 80.8 pcf
0
-5
-10
-15
-20
DEPTH
(in.)
1
10
100
1000
CONE INDEX (psi)
TEST #
12-29
13-29
16-29
Vesic'

FIGURE 5-3

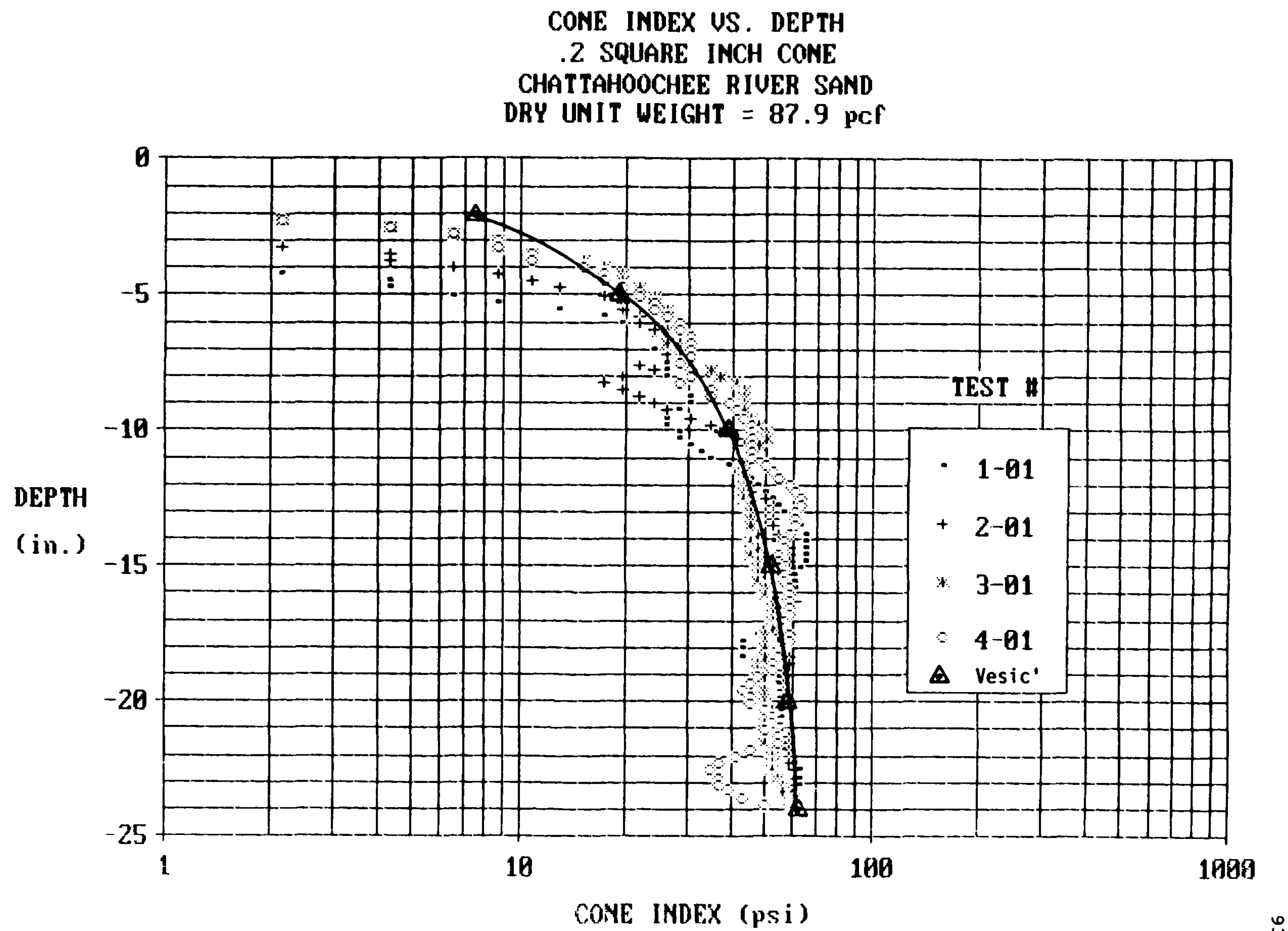
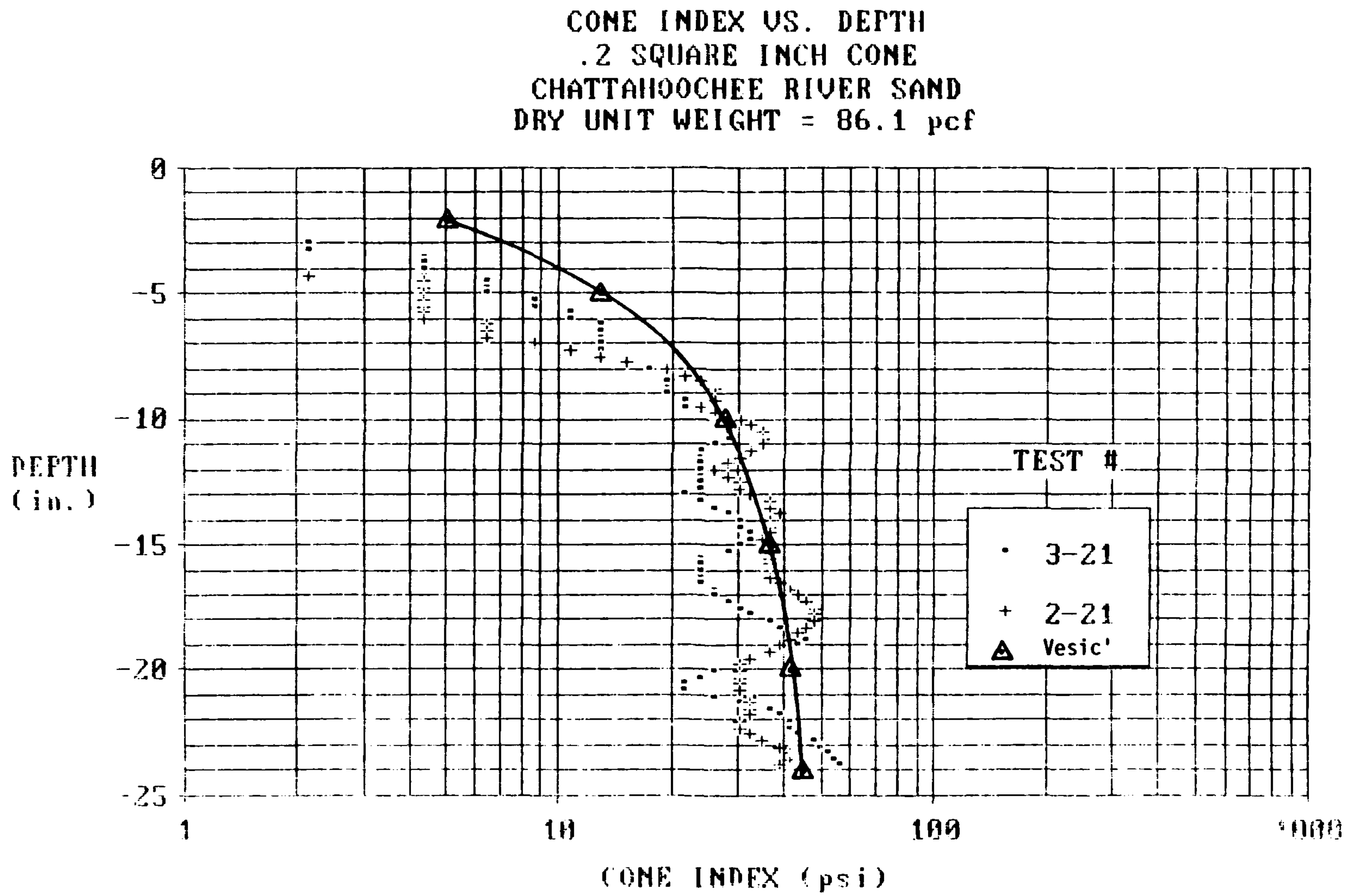

CONE INDEX VS. DEPTH
.2 SQUARE INCH CONE
CHATTAHOOCHEE RIVER SAND
DRY UNIT WEIGHT = 87.9 pcf
DEPTH
(in.)
0
-5
-10
-15
-20
-25
1
10
100
1000
CONE INDEX (psi)
TEST #
1-01
2-01
3-01
4-01
Vesic'

FIGURE 5-4



CONE INDEX VS. DEPTH
.2 SQUARE INCH CONE
CHATTAHOOCHEE RIVER SAND
DRY UNIT WEIGHT = 86.1 pcf
DEPTH (in.)
0
-5
-10
-15
-20
-25
1
10
100
1000
CONE INDEX (psi)
TEST #
3-21
2-21
Vesic'

FIGURE 5-5

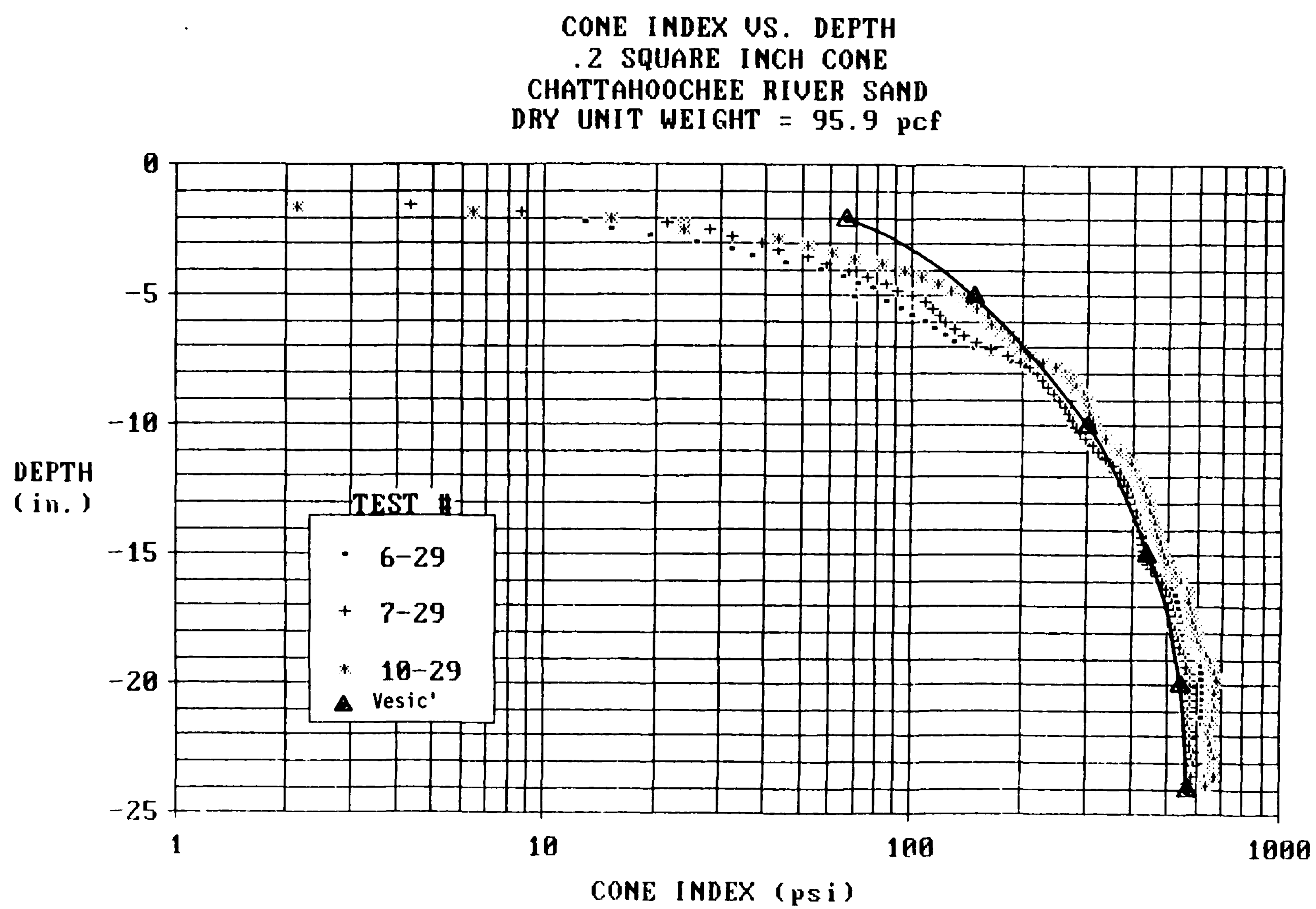

CONE INDEX VS. DEPTH
.2 SQUARE INCH CONE
CHATTAHOOCHEE RIVER SAND
DRY UNIT WEIGHT = 95.9 pcf
0
-5
-10
-15
-20
-25
DEPTH (in.)
TEST #
6-29
7-29
10-29
Vesic'
1
10
100
1000
CONE INDEX (psi)

FIGURE 5-6

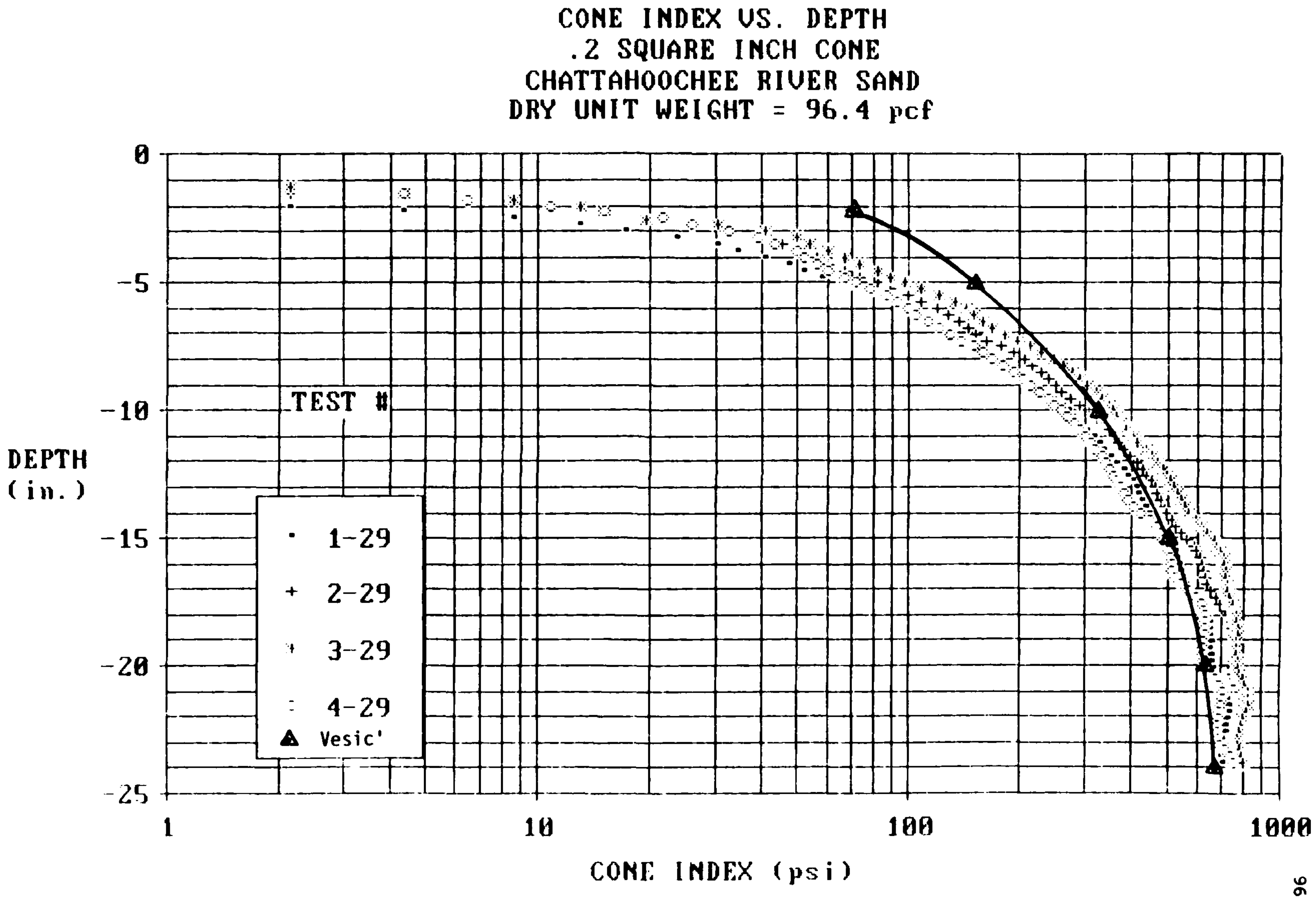

CONE INDEX VS. DEPTH
.2 SQUARE INCH CONE
CHATTAHOOCHEE RIVER SAND
DRY UNIT WEIGHT = 96.4 pcf
DEPTH (in.)
0
-5
-10
-15
-20
-25
1
10
100
1000
CONE INDEX (psi)
TEST #
1-29
2-29
3-29
4-29
Vesic'

FIGURE 5-7

This point deals with the smoothness of the curves established by Vesic'.

In Figure 4-3, Vesic' has depicted the relationship that the curves for cone resistance/index versus depth for all dry densities of the Chattahoochee River sand are very smooth. The validation testing program did not find this to be the case in all of the tests conducted. The results from the validation testing program demonstrate that at the higher dry densities the curves are expected to be relatively smooth; however, at the lower densities this would not be the expected case (Reference Figures 5-6 and 5-1, respectively). The reasons for the inconsistency in data between Vesic's test data and the data from this testing program stems from four possible areas: (1) non-uniform testing samples, (2) sensitivity of the measuring device, (3) the distortion of results by plotting on a semi-log curve, and (4) development of the best fit curve. Most likely the ultimate reason is related to a combination of all four factors as presented in the subsequent sections.

5.2.2 Non-uniform Density Samples

Changes of density states within a testing sample would be expected to exhibit corresponding changes in the cone index value. The plots for this validation testing program do demonstrate that the preparation of non-uniform dry density testing samples could possibly have caused the erratic

penetration traces. Work by Marcuson and Bieganousky (1976) demonstrates that it is difficult to achieve perfectly uniform density throughout a testing sample while utilizing the sample preparation techniques of this validation program and that used by Vesic'. Based on this observation, the sensitivity of the device measuring the cone index must be considered.

5.2.3 Sensitivity of the Device

The degree of non-uniformity in the data that will appear in the penetration traces is directly dependent upon the sensitivity of the measuring device. This point is especially true in the more loose density states which entail that the sensitivity of the measuring device be great enough to establish the slightest shift in resistance. The automated military cone penetrometer's 200 pound load cell exhibits a sensitivity of approximately 0.213%. Specifically, this sensitivity means that the cone index value which is stored in the data logger will change only when there is a total change in resistance measured of 0.426 pounds. This corresponds to a sensitivity of cone index of 2.13 psi for the .2 square inch cone and 0.852 psi for the .5 square inch cone. The sensitivity of the automated military cone penetrometer could be increased by using a smaller load cell which would enable more precise data to be gathered in the lower density states of the test sand. Thus, the sensitivity of the device establishes the reason for the straight lines and jumps in

resistance data for the loose samples.

5.2.4 Plotting Technique

Another reason for the apparent inconsistency in smoothness of the data deals with the fact that these plots are presented on a semi-log scale. Such a plotting technique could tend to distort the magnitude of the actual results. The scale of this plot is such that variance in penetration resistance data with depth at the lower densities appears to be greater than the data at the higher densities when in actuality the opposite is true. Because of this fact, a slight inconsistency in the density of the testing sample and therefore the cone index value at the lower dry densities will be magnified by this plotting technique while a similar change would be practically unnoticeable in the higher densities.

5.2.5 Best Fit Curve

Finally, the validation testing program data plots demonstrate that the penetration traces are erratic with the degree of variance decreasing with increasing dry density. From the literature review, this erratic behavior in the penetration traces of dry sands is to be expected (Parkin and Lunne, 1982). The scale of plotting these values could have some effect on the magnitude of erratic behavior in soil resistance. However, the

data presented by Vesic' does not exhibit any erratic behavior. Thus, it is speculated that the data in Figure 4-3 possibly exhibits an average value for the cone resistance values over a given depth depicted with the best fit semi-log plot for the respective dry densities of Chattahoochee River sand.

However, the inconsistency in smoothness of the plots for the present program is considered to be negligible in comparison to Vesic's data; therefore, the automated military cone penetrometer exhibits the ability to provide reliable and repeatable results in cone index determinations. Therefore, the plots from this validation testing program have qualitatively confirmed that the relationship between cone resistance and relative density of a dry sand does exist as established by Vesic' and reconfirmed by other works as discussed in section 4.2 of the previous chapter.

5.3 RATE OF PENETRATION EFFECTS

TM 5-330 states that the rate of penetration, either between operators or among penetrations in a specific soil type, should have no appreciable effect upon the measure of soil resistance or cone index. The manual also states that the preferred rate of penetration for the conventional penetrometer should be such that the operator is able to manually read four cone index values over a depth of 18 inches within 15 seconds in a soft soil. In addition, as stated in Chapter 2, the operator can stop pushing

the cone in conventional penetration testing to facilitate the recording of cone index values. Based on literature review of works conducted by Kamp (1982), Poskitt (1982), Turnage (1970), and Kok (1974), the rate of penetration has been shown to effect the results of penetration testing in soils. Therefore, a study of the effects this variable may have upon cone index measured by the automated military cone penetrometer was undertaken.

The works by Kamp and Kok dealt primarily with sandy soils while the testing conducted by Turnage and Poskitt dealt primarily with fine grained soils. All of the works, except that by Turnage, used a penetrometer by which the values of both cone and sleeve resistances could be obtained during a given sounding. In general, the conclusions of all these works show that the relationship between the rate of penetration and the resistance of the soil is nonlinear and the magnitude of the effect, if any, is dependent upon a number of parameters.

Specifically, these studies agree that the various physical and engineering properties of a particular soil and the magnitude of change in the rates of penetration seem to be the key parameters which determine the magnitude of effect that rate of penetration has upon cone index. These physical and engineering properties include the grain-size distribution, the percent of clay size particles, the degree of saturation, the possibility of drainage within the strata, and the viscosity of the soil (Kamp, 1982; Kok, 1974; Turnage, 1970). In general, all of these properties play a key role in the formulation of the expected

angle of internal friction which in essence establishes the shearing resistance of the soil matrix and thus the expected magnitude of the measured cone resistance (Villet and Mitchell, 1981). Kamp's work stipulates that the one key factor in determining the effect of the rate of penetration on resistance values in clean sands is the "extent to which pore water pressure changes may develop around the cone". (Kamp, 1982) This same basic conclusion was presented by Campanella and Robertson (1982) in their research at the University of British Columbia on conventional Cone Penetration Testing (CPT).

The tests conducted in the variable testing program were all performed on the same sand in a dry condition; therefore, the gradation properties are identical and the generation of pore pressure is not possible. Using a maximum range of 4 inches per minute to 8 inches per minute (factor of 2) within a given test series, the rate of penetration is roughly analyzed in each of the density states. The 4 inches per minute rate of penetration was used to simulate the tests by Vesic' who used this same rate to establish the data depicted in Figure 4-3.

All of the data obtained during this phase of the testing program qualitatively demonstrates that the rate of penetration does not appear to have any noticeable effect on the cone resistance values in a dry Chattahoochee River sand. Figures 5-8 for loose, 5-9 for medium, and 5-10 for dense samples are representative of the data collected in this phase of the program. The remaining data plots for this phase of testing are

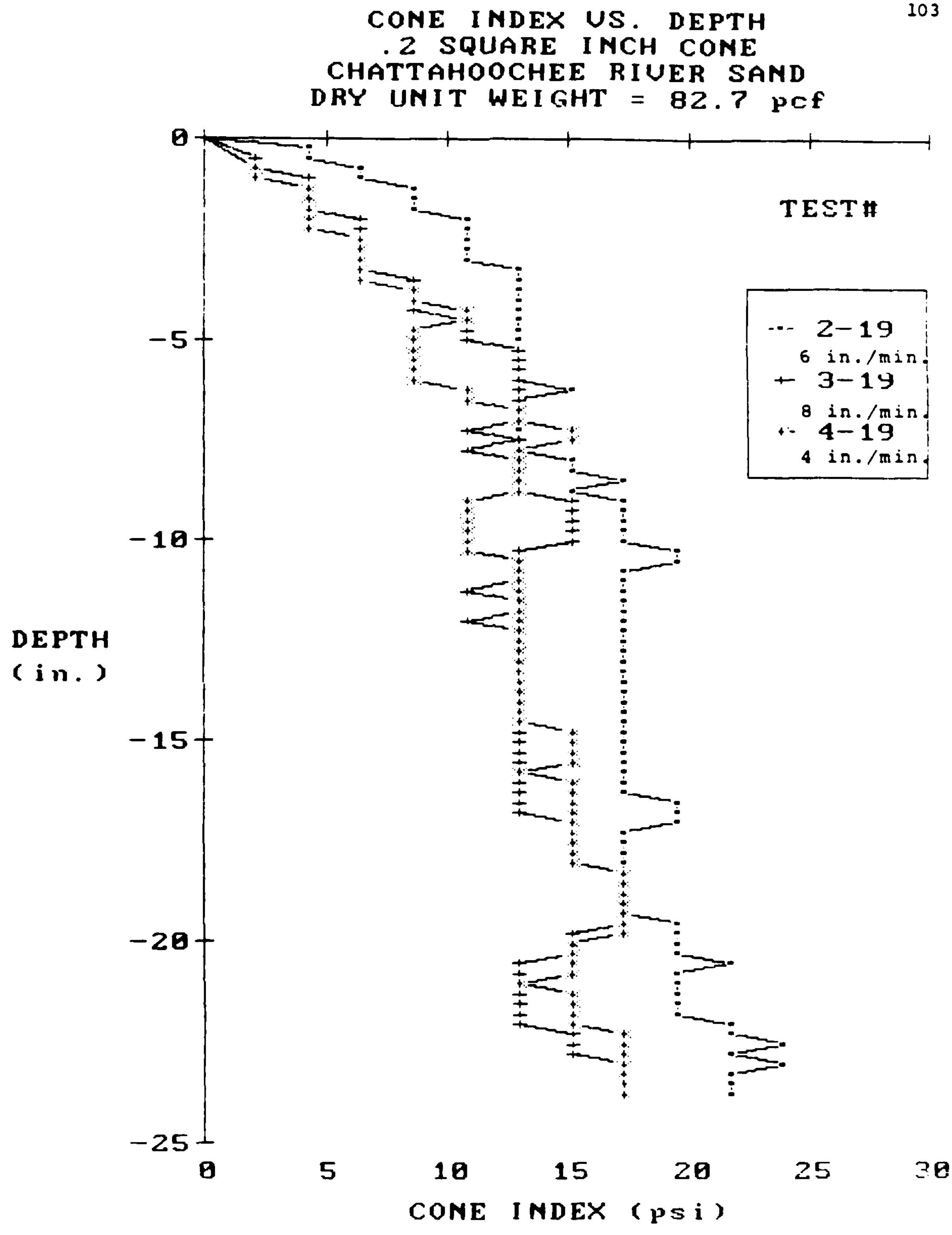


FIGURE 5-8 RATE OF PENETRATION - LOOSE SAMPLE

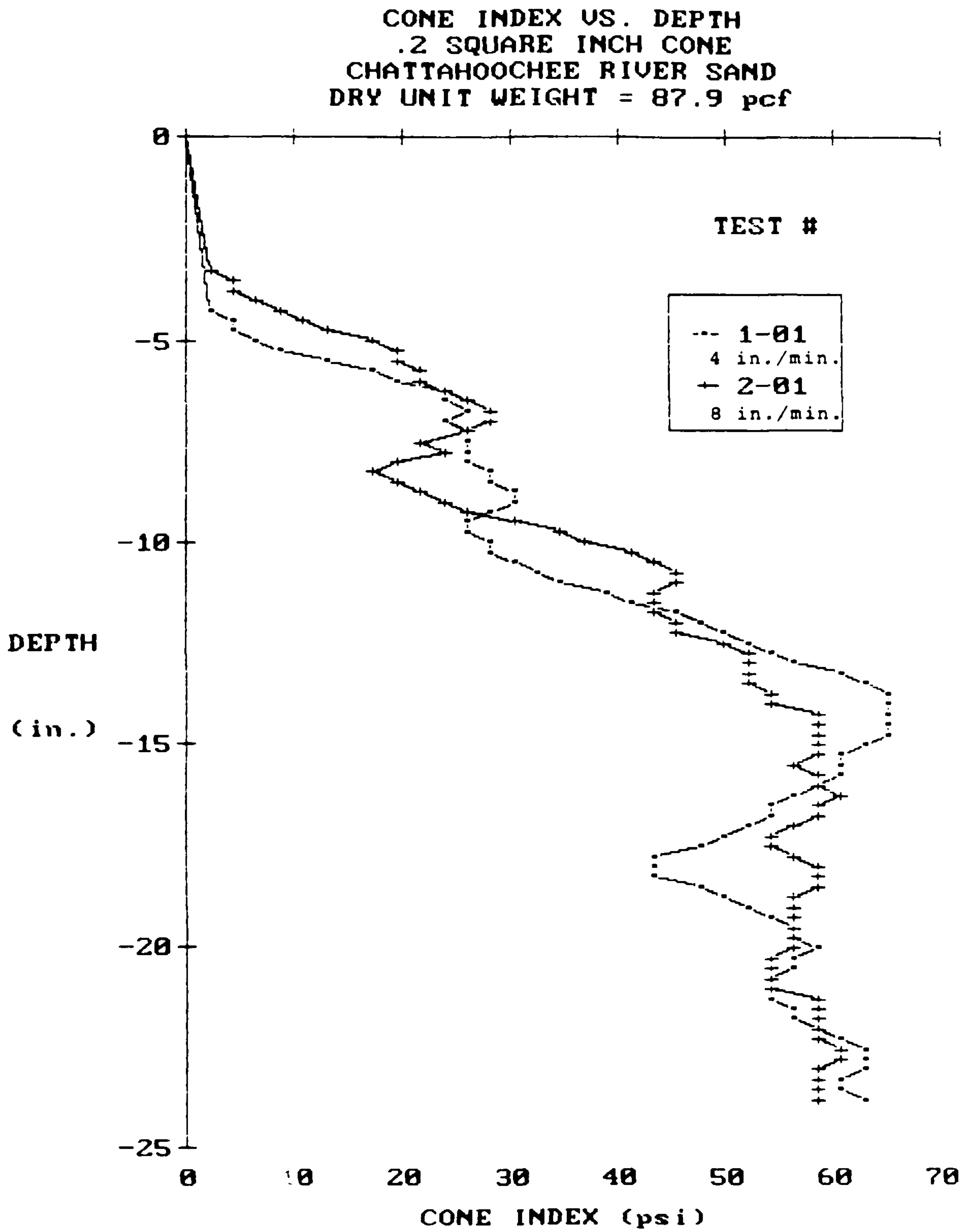


FIGURE 5-9 RATE OF PENETRATION - MEDIUM SAMPLE

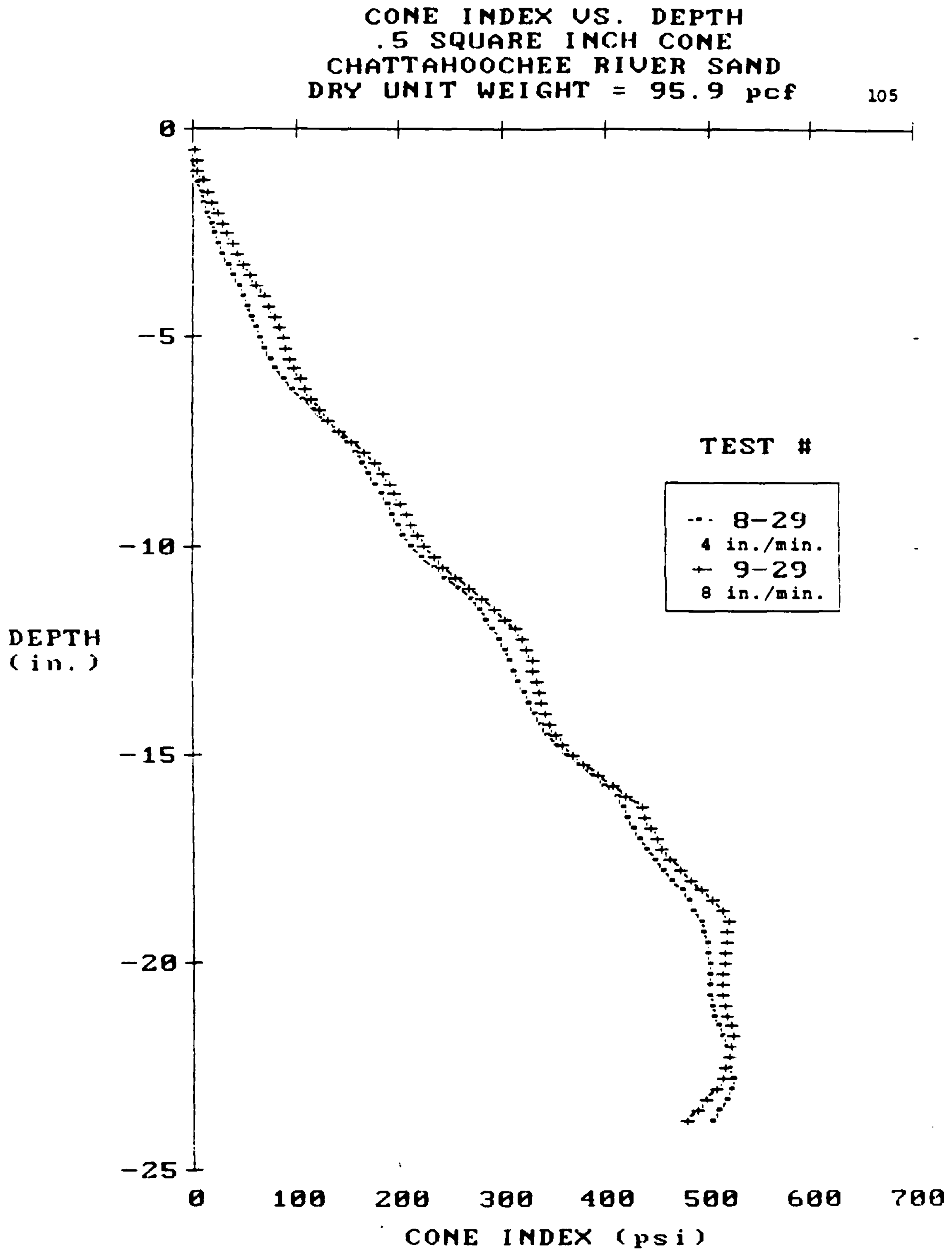


FIGURE 5-10 RATE OF PENETRATION - DENSE SAMPLE

located in Appendix B for further reference. Specifically, this data provides the basis by which the conclusion is drawn that small variations in speed have no significant effect on the cone index for dry sands. This may not necessarily be the case, however, if the magnitude of change in the rate of penetration is possibly increased to a factor of 10 as used by Kamp. However, such a high factor would not be in compliance with the ASTM standard variance of ± 25%. In addition, the lack of saturation in the testing sample may possibly have been another reason for the observation of no noticeable effects. This conclusion is based on the observations of other works as previously stated. A testing program with a chamber capable of controlling the saturation of the testing sample is required to enable a more effective analysis of this topic.

5.4 EFFECT OF CONE SIZE

The effect of the overall cone shape on the value of cone resistance observed has been studied by Kok (1974) and Villet and Mitchell (1981). DeRuiter (1982) reviewed these works and concludes that the overwhelming factor of the cone shape's effect on the value of cone resistance concerns the ratio of the cone diameter over the diameter of the shaft (Dc/d_s). The standard ratio is presented as $Dc/d_s = 1$. DeRuiter concludes in his work that in general a ratio of $Dc/d_s > 1$ will cause the cone resistance value to be lower than expected because of the annular

space created directly behind the penetrating cone. Villet and Mitchell's (1981) results establish the opposite to be true.

The present testing program utilizes the standard 3/8 inch diameter steel shaft with both the .5 inch and the .799 inch diameter cones to examine the effect of cone size on soil resistance. The .5 inch diameter cone establishes a ratio of Dc/d_s approximately equal to 1, for all practical purposes, while the .799 inch diameter cone exhibits a ratio of $Dc/d_s > 1$.

The test data demonstrates in the very loose, dry Chattahoochee River Sand samples (Dr = 17%) that tests with cone to shaft diameter ratios (Dc/d_s) of unity exhibited consistently less cone resistance than tests with ratios greater than one. Figures 5-11, 5-12, and 5-13 depict this fact. The reason for this is explained by analyzing and understanding the applicable terms in the general bearing capacity equation. For all practical purposes, this equation for cone penetration tests conducted in dry sands is reduced to:

$$\text{Cone Index} = \frac{\gamma B}{2} N_\gamma$$

Based on this equation, it is obvious that for a test sample at a given dry density the only term which changes is "B" (either .5 or .799 inches). Thus, as the size of the cone increases the value of cone index should also increase. This conclusions seems to be in agreement with the results presented by Villet and Mitchell.

The test data in the very dense dry Chattahoochee River Sand

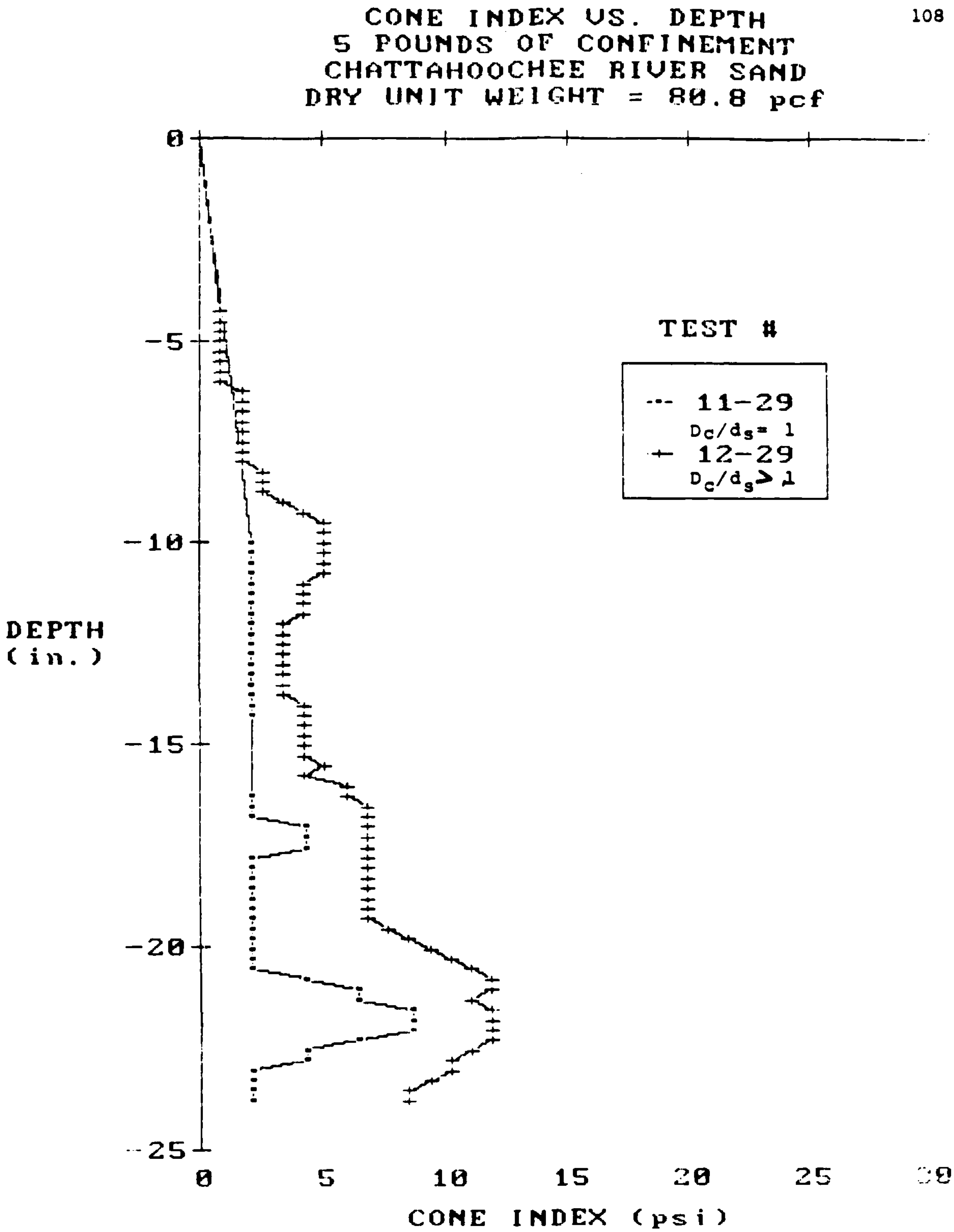


FIGURE 5-11 EFFECT OF CONE SIZE IN LOOSE SAMPLES

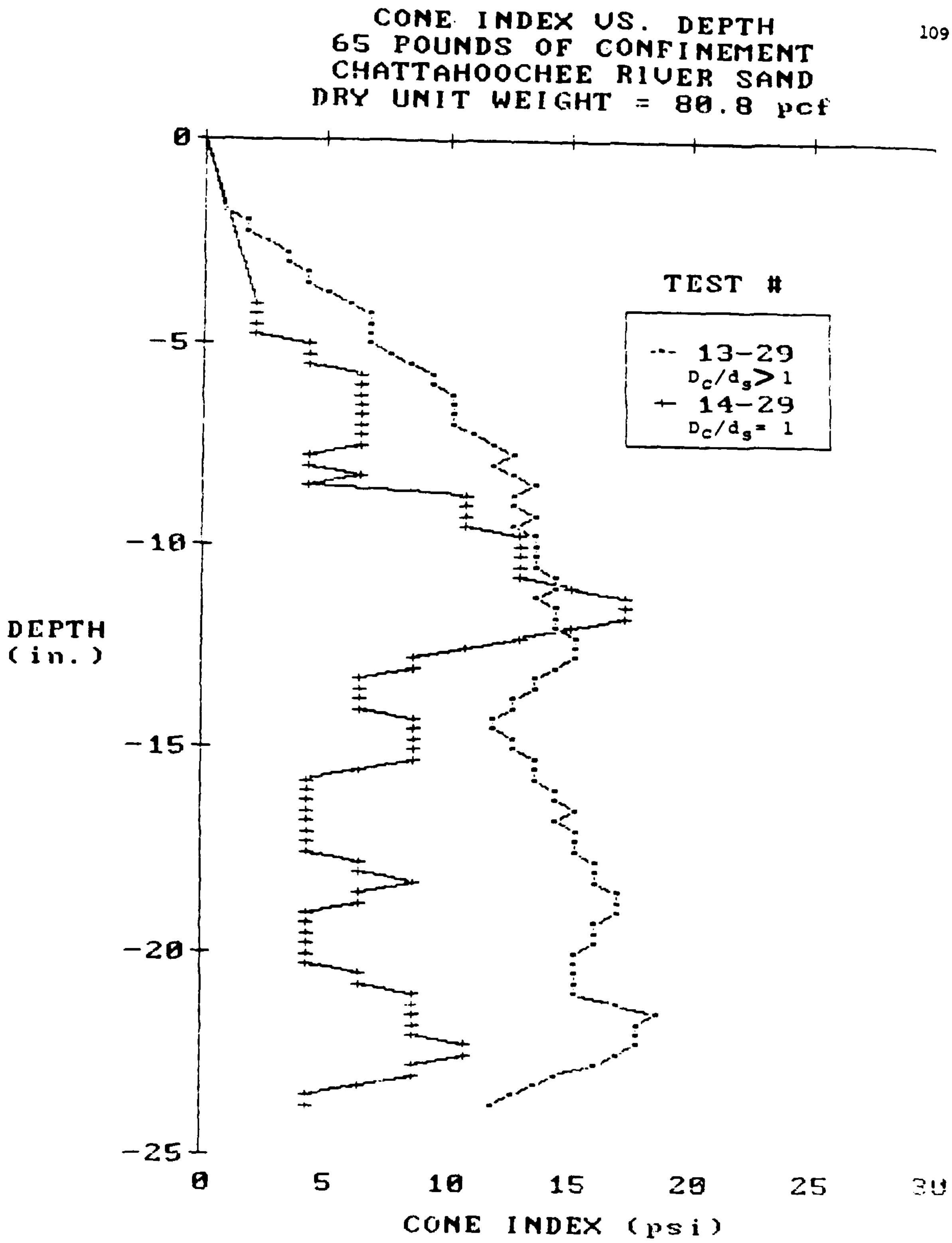


FIGURE 5-12 EFFECTS OF CONE SIZE IN LOOSE SAMPLES

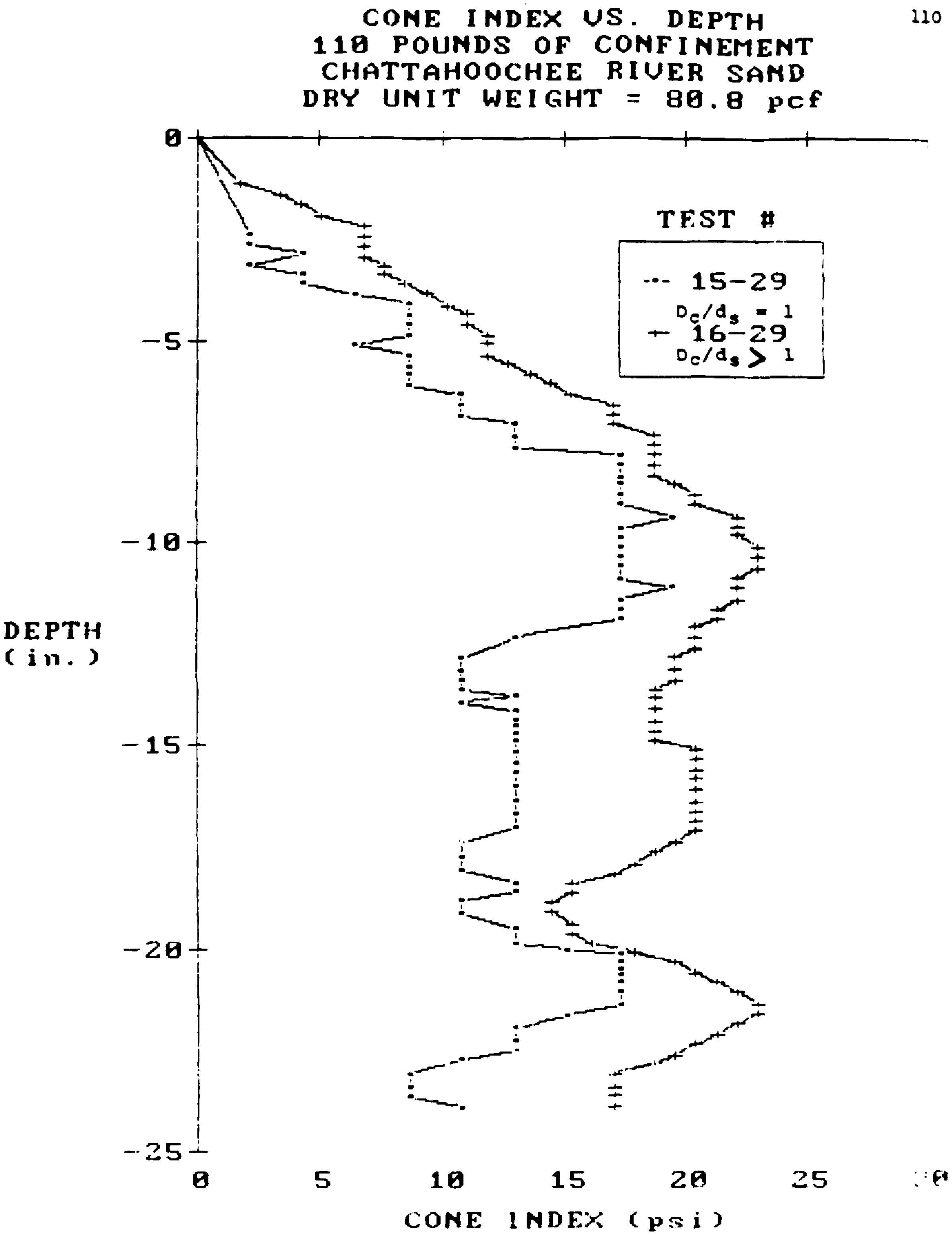


FIGURE 5-13 EFFECTS OF CONE SIZE IN LOOSE SAMPLES

samples (Dr = 95%) does not demonstrate the same findings as established with the very loose samples. In these samples, the test data collected with cone to shaft diameter ratios (Dc/d_s) greater than one exhibited consistently less cone resistance than test data collected with ratios of unity. Therefore, the larger cone did not establish the larger value of cone index. Figure 5-14 depicts the basis for this conclusion. It is proposed that this conclusion is directly related to the fact that very dense sands demonstrate a tendency to dilate during shear; therefore, tests conducted with the penetrating .799 inch diameter cone (a diameter ratio greater than one) provide an open space which allows this volume change to more readily occur. However, the .5 inch diameter cone establishes a diameter ratio approximately equal to one which means that the dense sand is more confined during penetration and is not provided with an open space to allow substantial dilation. Thus, the tests conducted with a diameter ratio approximately equal to one resulted in higher cone resistance values than those tests conducted with a diameter ratio greater than one.

The observations in the medium density state do not provide as clear a conclusion on the effects of cone size as did the data in both the loose and the dense states. Figure 5-15 shows that the ratio of $Dc/d_s > 1$ exhibits data which is less than that of the ratios of unity. Figure 5-16 shows that the data for the ratios of unity are less. This variance in data is possibly attributed to the non-uniformity in the density of the sample;

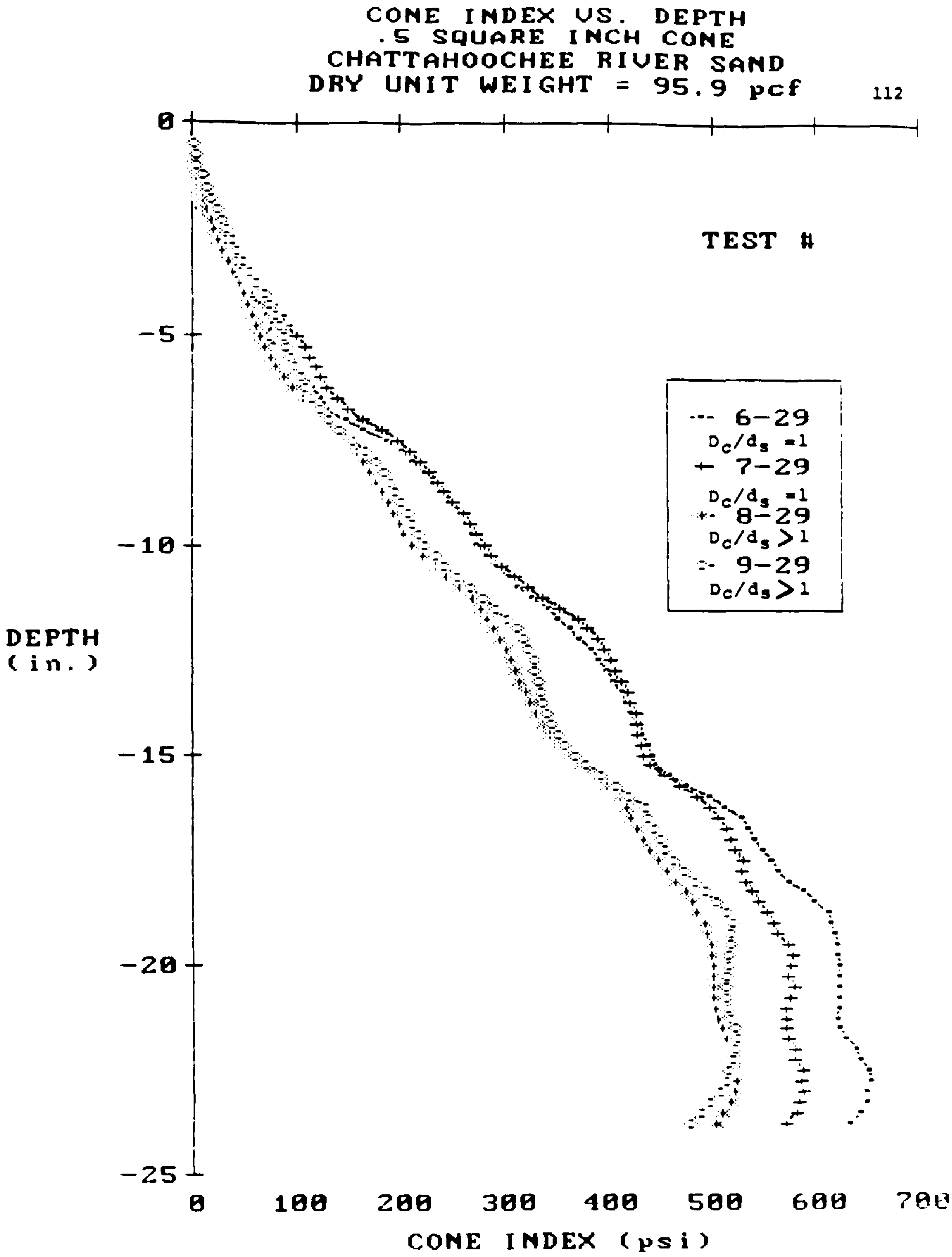


FIGURE 5-14 EFFECTS OF CONE SIZE IN DENSE SAMPLES

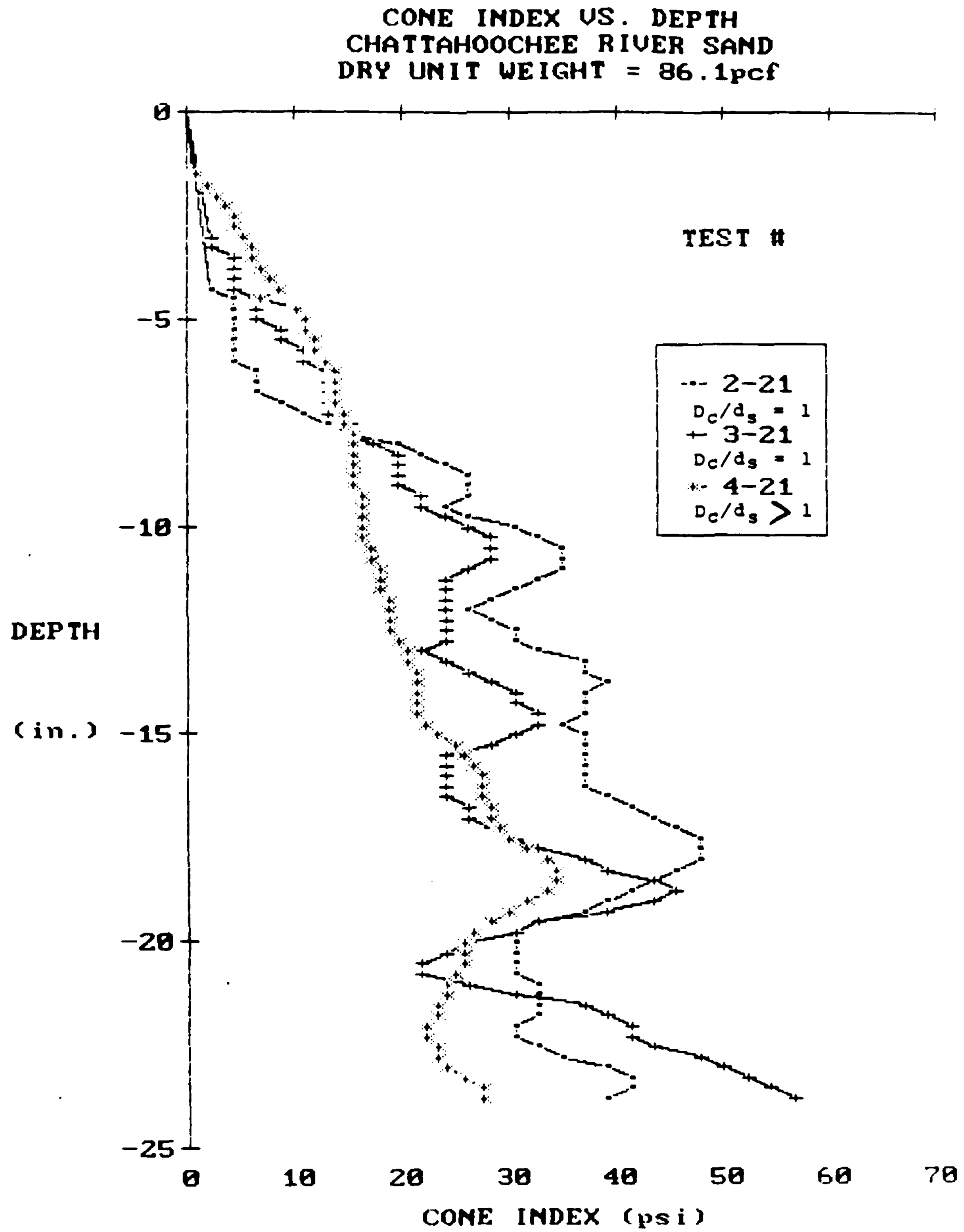


FIGURE 5-15 EFFECTS OF CONE SIZE IN MEDIUM SAMPLES

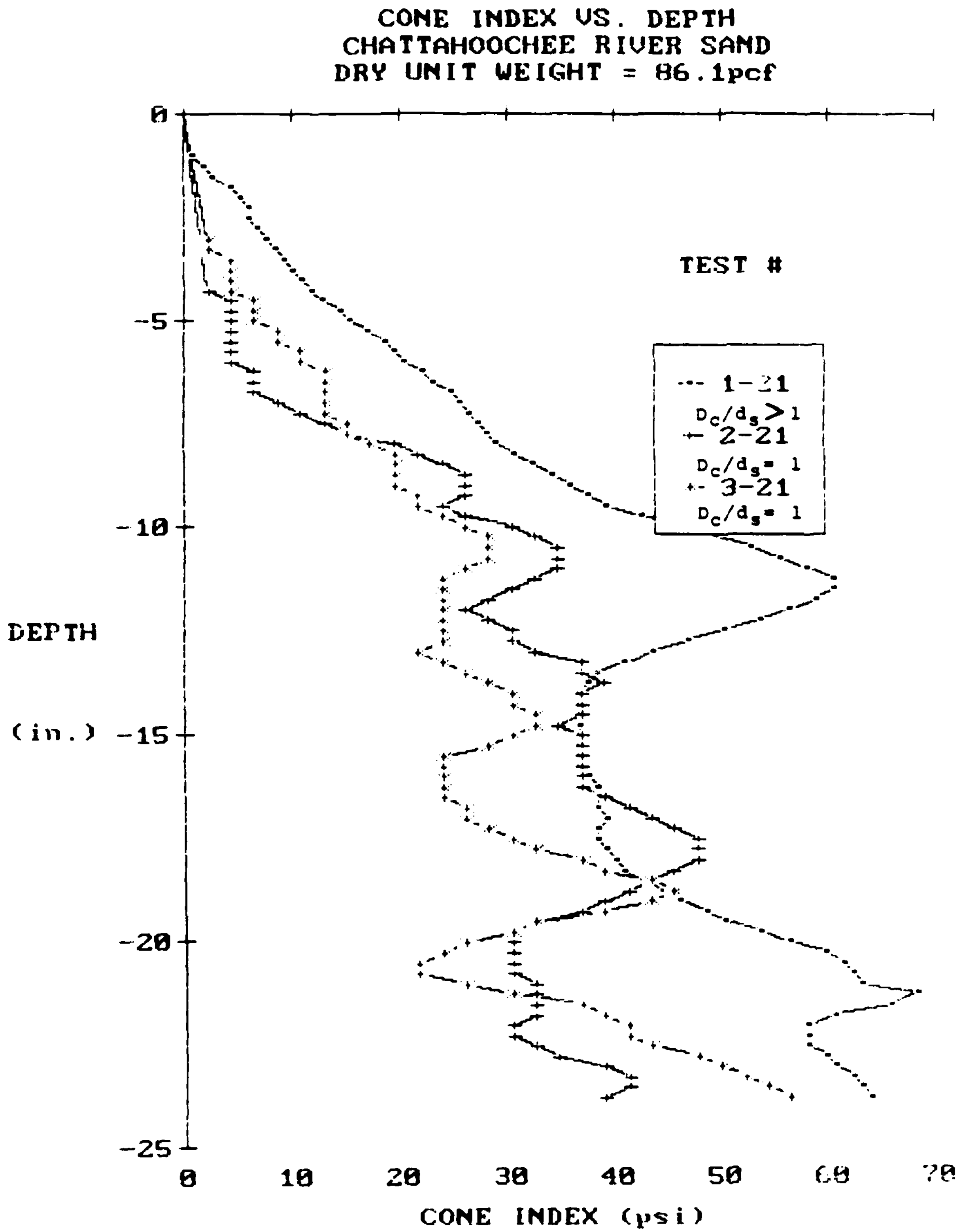


FIGURE 5-16 EFFECTS OF CONE SIZE IN MEDIUM SAMPLES

therefore, this data is not considered adequate in developing conclusions on the effects of cone size on soil resistance.

In conclusion, the data observed in this testing phase on the effects of cone size on soil resistance provides the basis for two specific conclusions. First, in very dense dry Chattahoochee River sand samples (Dr = 95%), the data for cone to shaft diameter ratios (Dc/d_s) greater than one exhibit consistently less cone resistance than the data for Dc/d_s ratios of unity. Second, the opposite is concluded for very loose samples (Dr = 17%). This phase of the testing program demonstrates that the automated military cone penetrometer is sensitive enough to measure subtle variations in soil resistance to establish the above analyses and conclusions. Therefore, this device should be considered for further research in this area of concern.

5.5 EFFECT OF CONCENTRATED SURFACE LOADS

The purpose of this phase of the testing program is to study the effects, if any, that the weight of the cone penetrometer's operator has upon the measured soil resistance. The soils of most interest to military trafficability studies are those which exhibit weak or soft conditions within the upper 24 inches of the soil mass. Therefore, this shallow depth of interest coupled with the fact that the operator is required to stand in close proximity of the penetrating cone to conduct the penetration test

establishes the basis for analyzing the influence of the operator's weight on the measured cone index.

The concept of the analysis in this phase of the testing program takes into account Boussinesq's (1883) solution to the problem of increases in vertical stresses with depth due to a point load at the surface of a homogeneous, elastic, and isotropic medium. From Boussinesq's solution, it is anticipated that the change in vertical pressure below the ground surface will increase to a critical depth and then tend to decrease until the effect is relatively negligible. According to work conducted by Villet and Mitchell (1981) in a testing chamber providing uniform stress control, increases in vertical stresses are associated with increases in cone tip resistance. It is noted that an increase in vertical stress also increase the lateral stress in the soil samples.

The effects of increasing concentrated surface loads on cone resistance in this testing program are analyzed in the very loose and dense test samples. The following three concentrated loads are utilized in this analysis: 5, 65, and 110 pounds. As previously stated, these loads are applied on each side of the cone at the same location that the operator would place his feet on the foot rest in the conduct of a sounding. Five and ten pound circular lead weights approximately six and eight inches in diameter, respectively, are used to establish the 5 and 65 pound loads. The 110 pound point load requirement is accomplished by having the researcher conduct the sounding for various tests.

As expected, the data observed in the loose state exhibits an increase in cone resistance value with increasing concentrated surface load. Figures 5-17 and 5-18 present the results of this analysis for the .2 and .5 square inch cones, respectively. The increasing surface loads provided incremental increasing confinement due to application at the surface and the increase in lateral stress within the sample. Tests were conducted with both the .2 and .5 square inch cones in this loose state and both exhibit consistently similar results.

For the tests conducted in the dense state, only the 5 and 110 pound point loads with the .2 square inch cone are considered. Figure 5-19 for the test sample at a dry density of 95.9 pcf provides data which establishes an observation that increasing vertical stress causes increasing cone resistance over the full critical depth of 24 inches. This observation is in total agreement with the loose density results stated above. However, this is not the observation drawn from the data in Figures 5-20 and 5-21 for the test sample at a dry density of 96.4 pcf. The data in these figures exhibit the observation that the increase in vertical stress tends to increase the value of cone resistance to an approximate depth of 14 to 16 inches and then tends to be less than the data observed for the smaller vertical stress. This observation could possibly be the effect of non-uniform density within the testing chamber or possibly due to boundary effects. The possibility of the boundary effects is based on the findings presented in Chapter 4, and the fact that

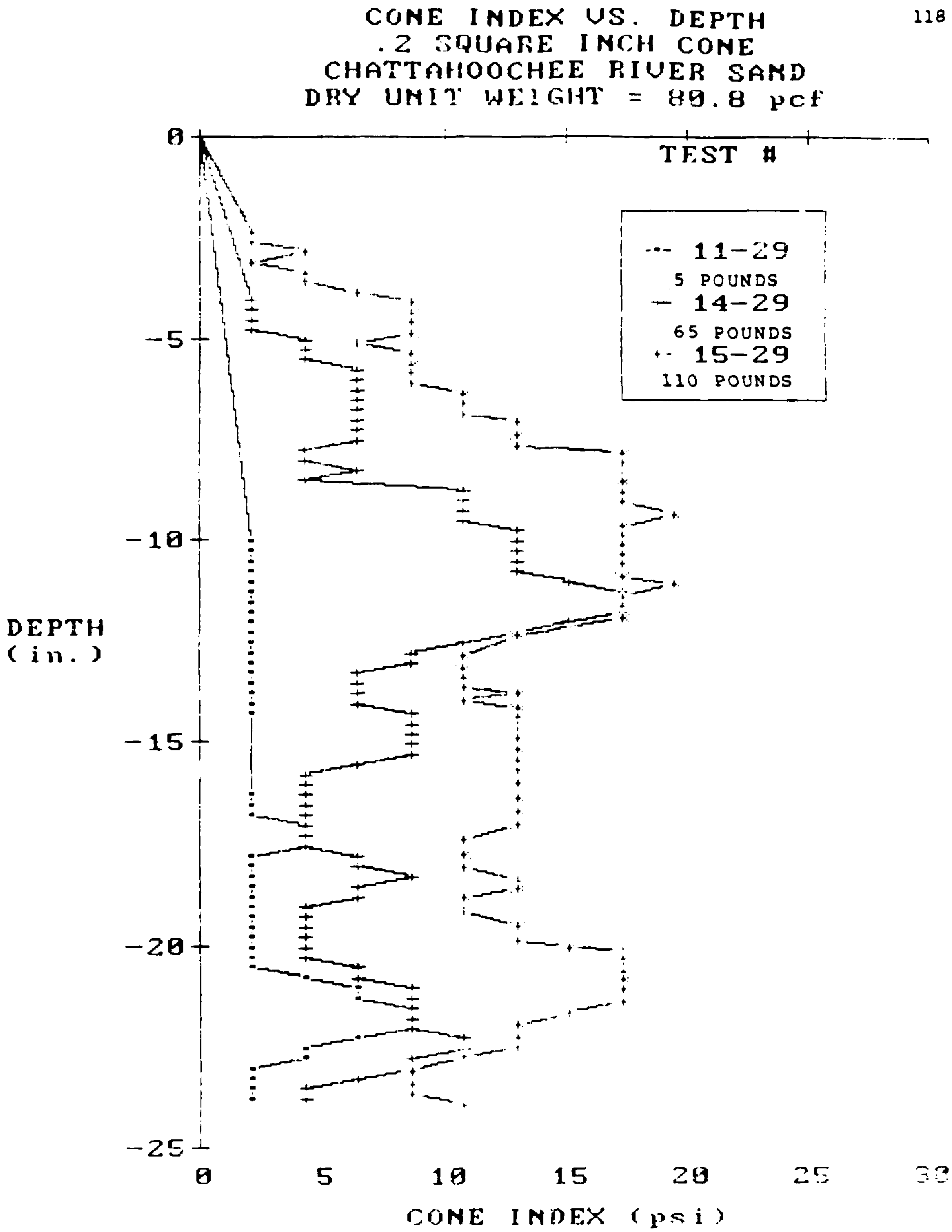


FIGURE 5-17 EFFECTS OF CONCENTRATED SURFACE LOADS

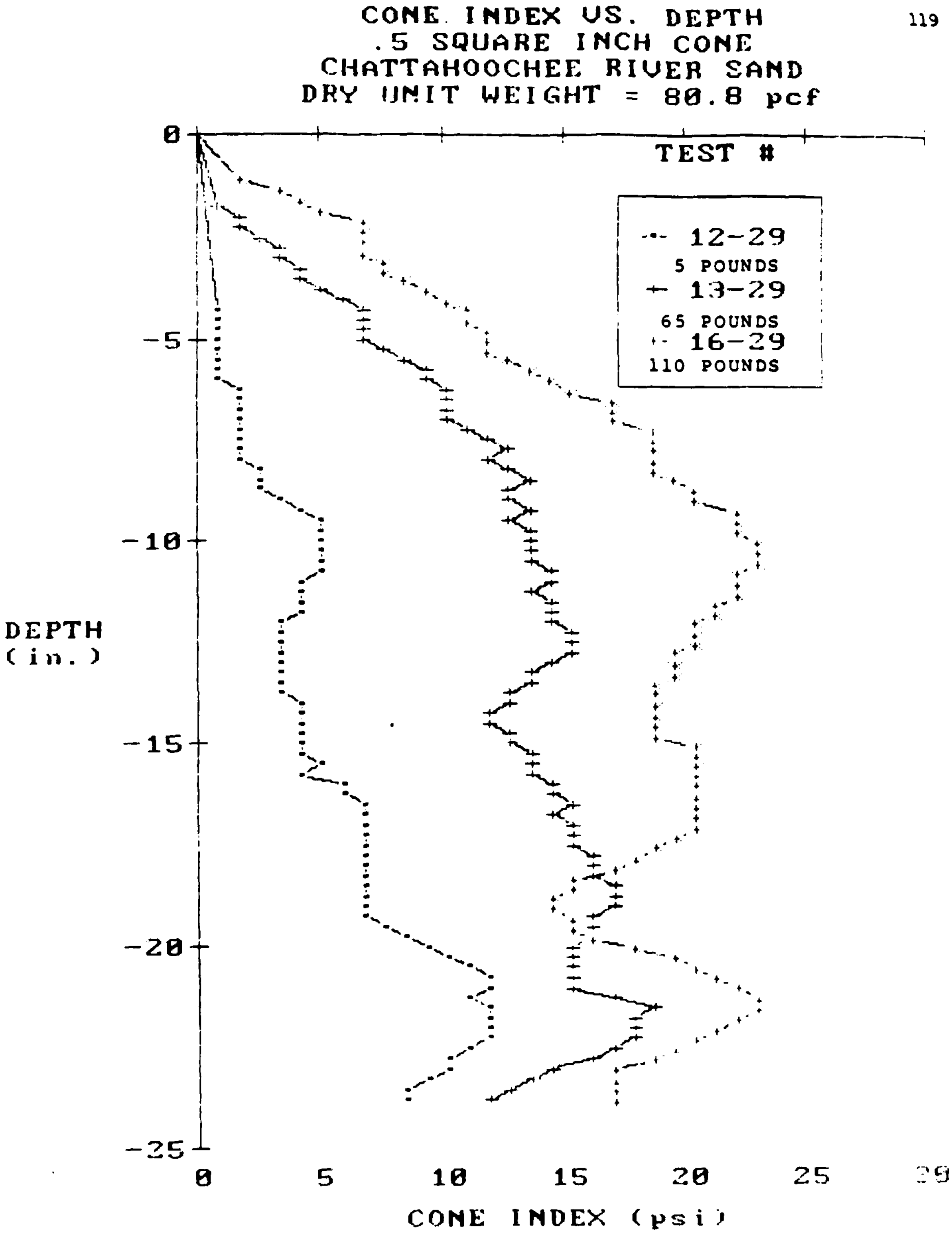


FIGURE 5-18 EFFECTS OF CONCENTRATED SURFACE LOADS

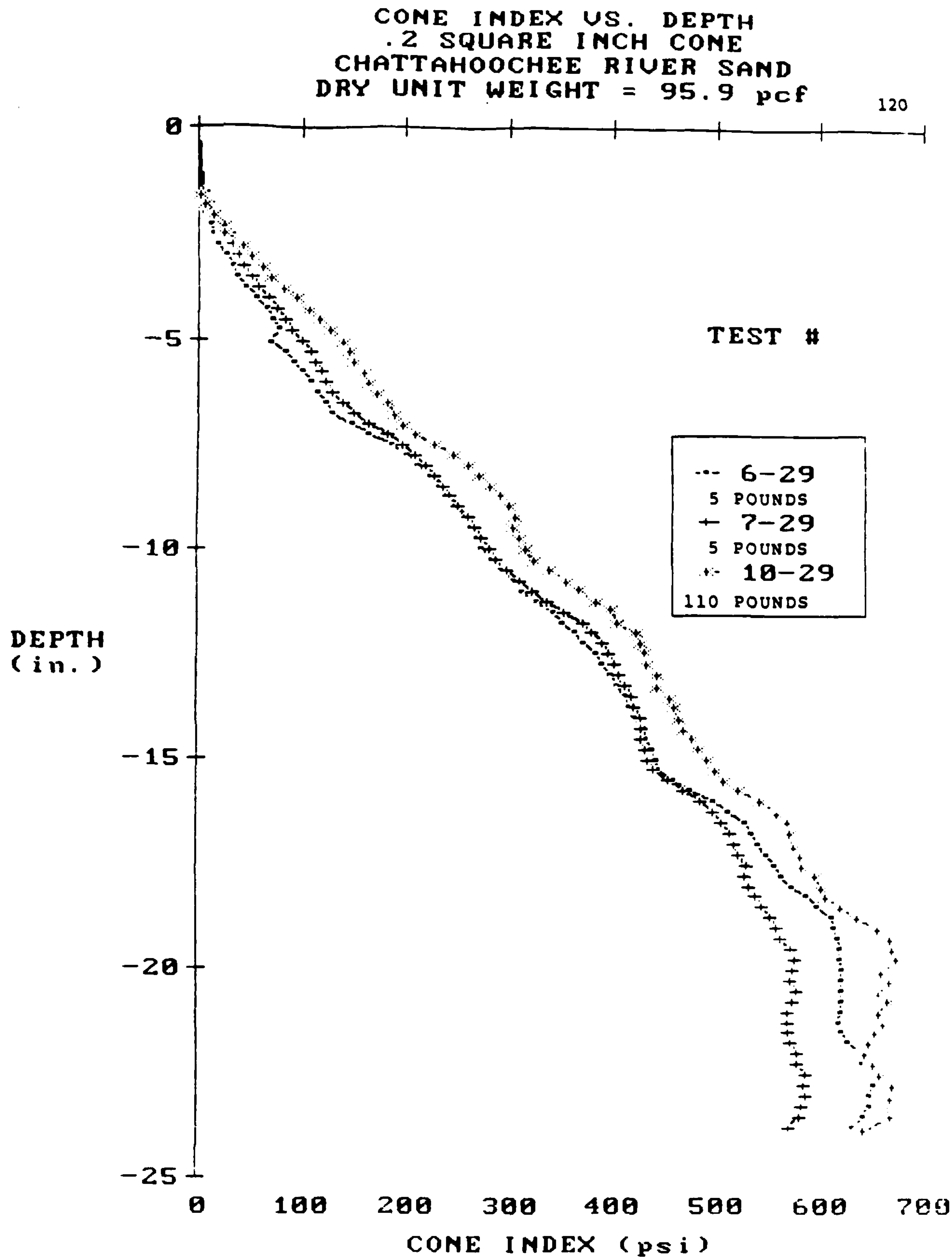


FIGURE 5-19 EFFECTS OF CONCENTRATED SURFACE LOADS

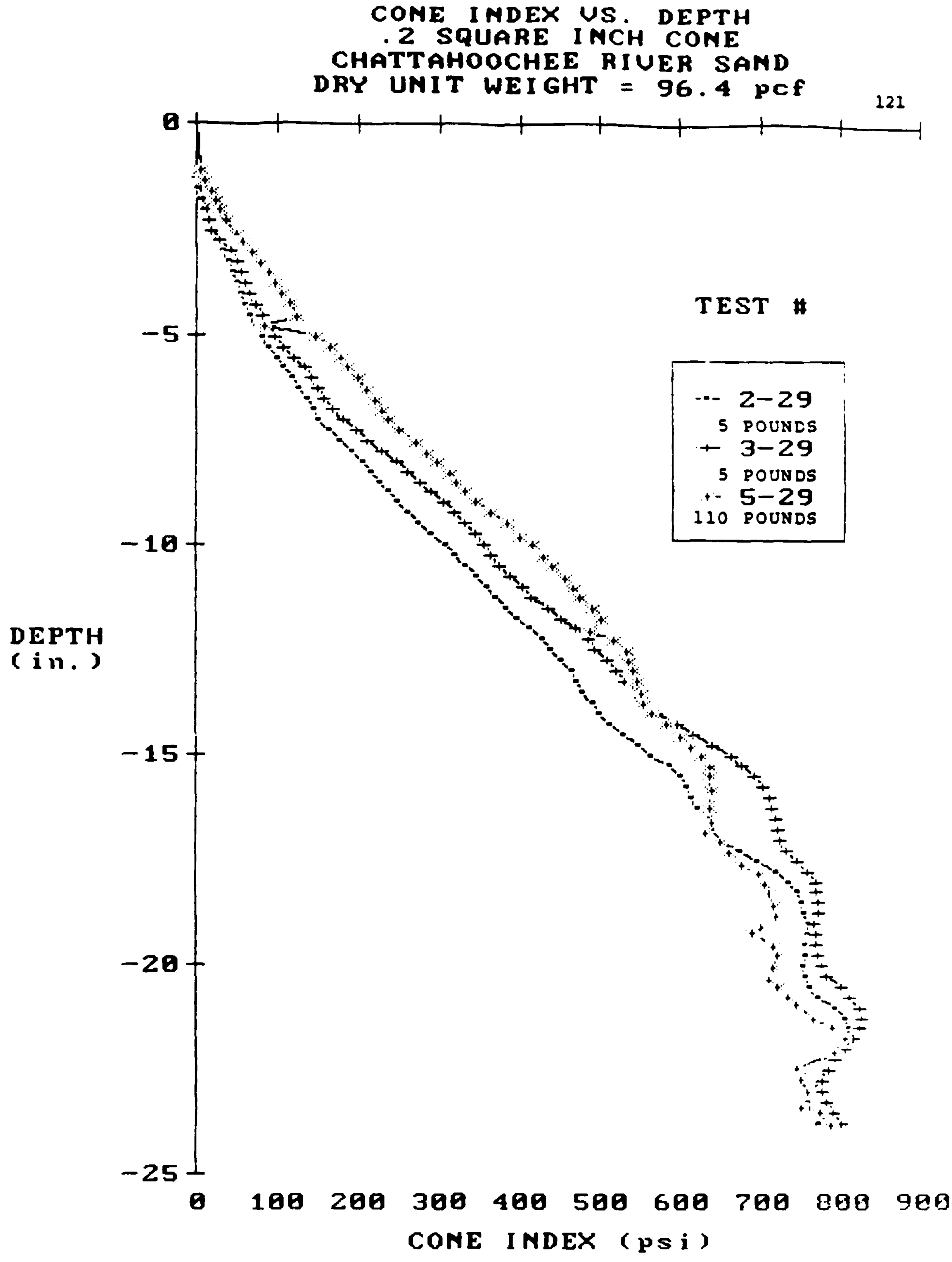


FIGURE 5-20 EFFECTS OF CONCENTRATED SURFACE LOADS

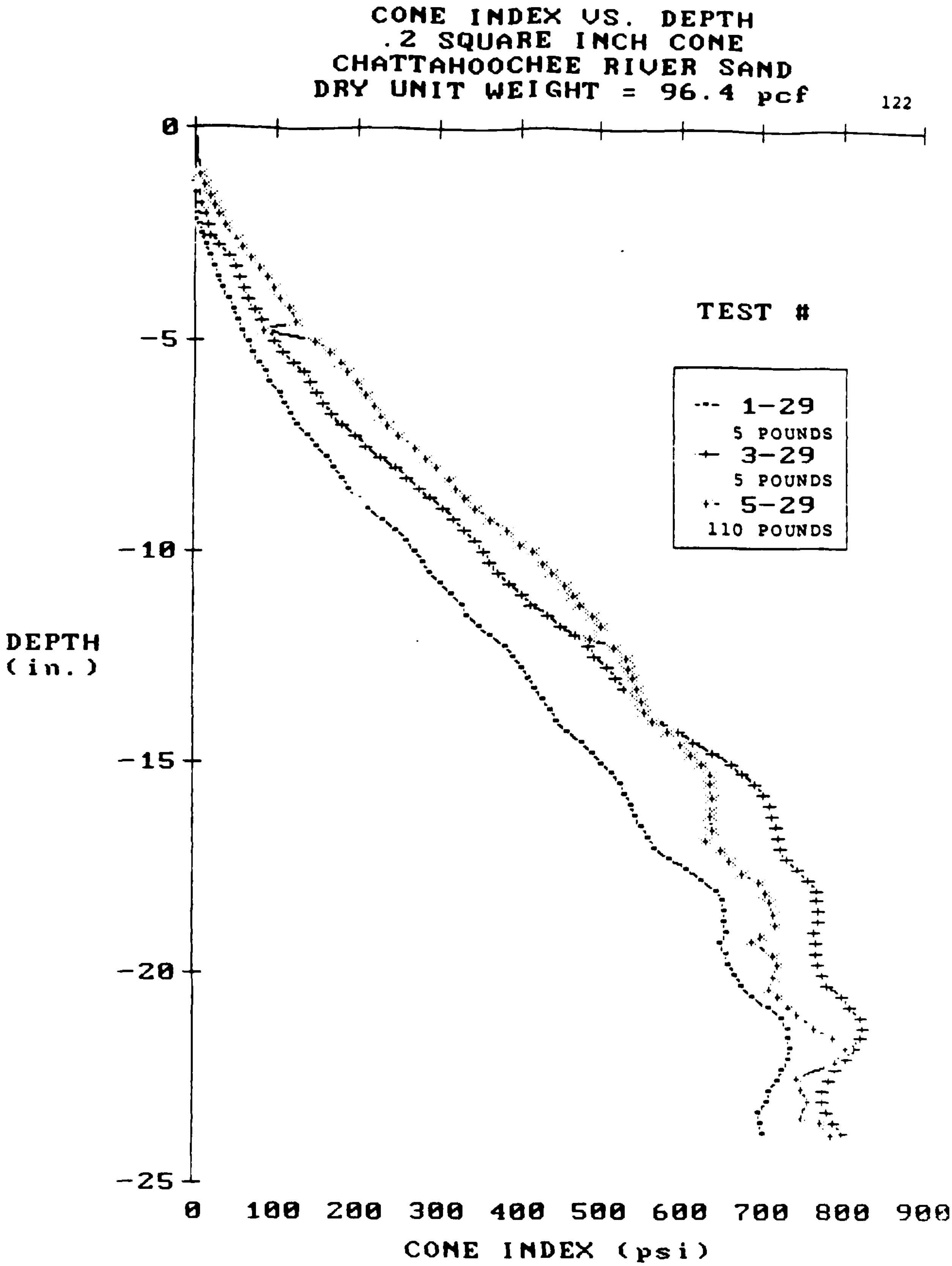


FIGURE 5-21 EFFECTS OF CONCENTRATED SURFACE LOADS

the 110 pound point load penetration was conducted in the center of the testing chamber while the 5 pound point load penetrations were conducted closer to the edge of the chamber. Therefore, the penetrations with the 5 pound point loads possibly exhibit higher values of cone resistance due to the influence of the testing chamber's boundary causing the cone to feel additional lateral stress.

5.6 COMPARISON TO WES ANALYTICAL MODEL

An in-depth study analyzing the application of the WES analytical model and subsequent equations developed by Baladi and Rohani (1981) was not within the original scope of this initial testing phase for the automated military cone penetrometer. However, because of the broad data base of engineering properties published from previous research conducted on Chattahoochee River Sand, a comparison of the cone index values measured during the conduct of this test to those established with the model was attempted.

The equations developed by Baladi and Rohani (1981) using the WES analytical model propose that the cone index with depth of a granular soil (cohesion = 0) can be predicted as follows:

$$CI = \frac{2 \tan \alpha (1 + \sin \phi) \bar{G}^{m}}{\left(\frac{D}{2} \gamma\right)^{2} \tan^{3} \phi} \left[\frac{3(\tan \alpha + \tan \phi)}{3 - \sin \phi}\right] \Omega$$

where

$$\Omega = \frac{[\gamma(Z+L)\tan\phi]^{3-m} - [\gamma(Z+L)\tan\phi + (2-m)\gamma L\tan\phi](\gamma Z\tan\phi)^{2-m}}{(2-m)(3-m)}$$

D = diameter of cone
L = length of cone
2 = apex angle of cone
Z+L = surface to tip of cone
m = 4 sinϕ/3(1+sinϕ)

and $$\tilde{G} = 0.5\left[A + \frac{1 - B\exp(-\beta Z)}{1 + B\exp(-\beta Z)}\right]G$$

G = apparent shear modulus
A = 0.986 (for conventional WES cone)
B = 100 (for conventional WES cone)
B = 0.55 $(in)^{-1}$ (for conventional WES cone)

From the above equations it is apparent that the cone index is directly related to the strength properties of the soil in question. The development of such a relationship is encouraging from the aspects of trafficability studies as well as other geotechnical engineering applications .

Specific properties of the Chattahoochee River sand were established using research conducted by Boutwell (1965) and Vesic' (1963). Specifically, these properties were used in the above analytical equations to predict the cone index values for two Chattahoochee River Sand test sample densities. The dry

densities and strength properties used are as follows:

Density (pcf)	Shear Modulus (psi)	Friction Angle, degrees
86.1	30	32
95.9	1150	43

A Poisson's ratio equal to 0.35 was used in the calculations.

As depicted in Figures 5-22 and 5-23, the predicted cone index values derived from using the WES analytical model agree favorably with the actual measured values obtained during the conduct of the laboratory testing program. Note that the scale range between these two plots is nearly tenfold and that the sensitivity of the automated military cone penetrometer allows effective data to be established in each. Therefore, the automated military cone penetrometer is considered an excellent tool to conduct further research on this topic using a variety of soil types.

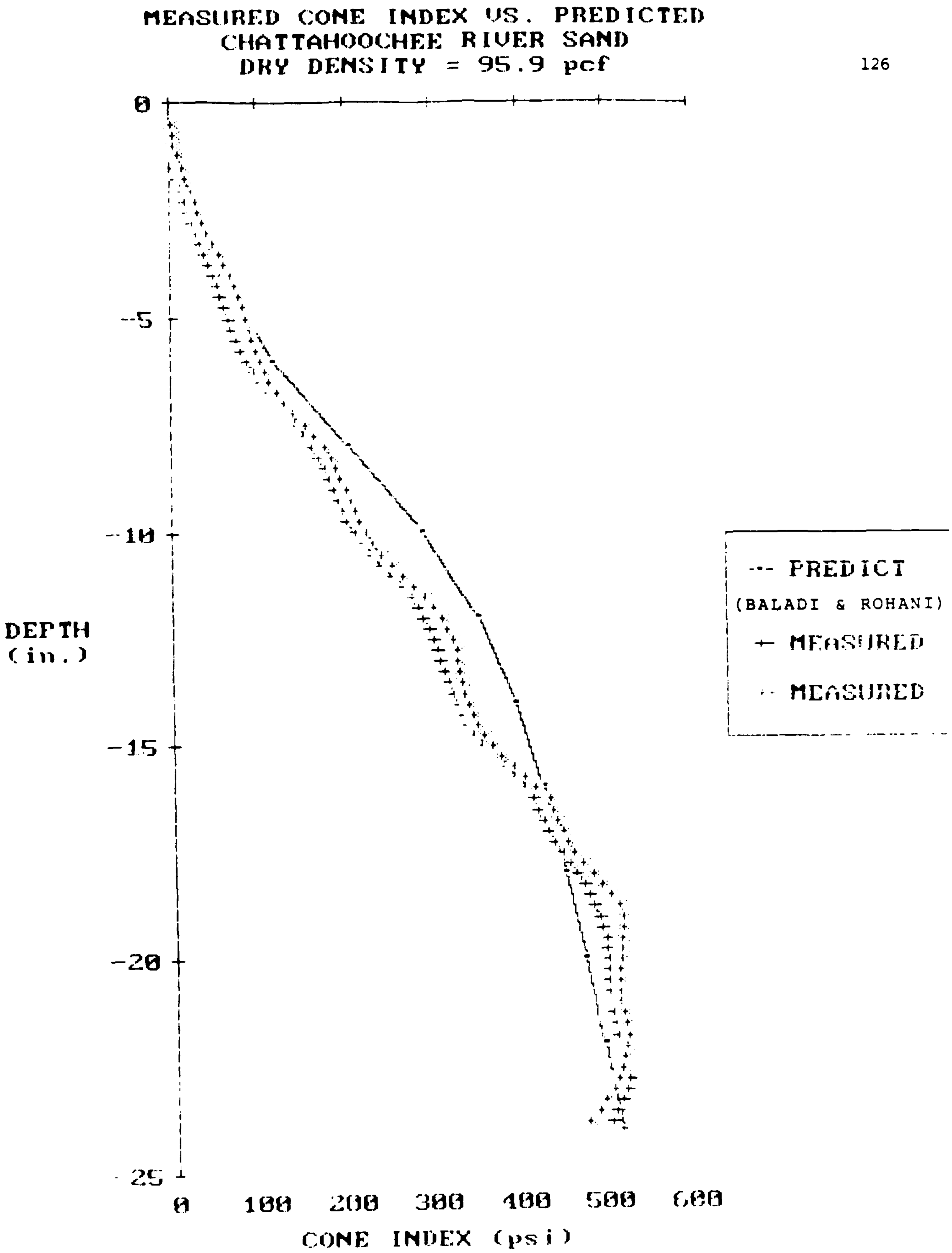


FIGURE 5-22 COMPARISON BETWEEN PREDICTED & ACTUAL CI

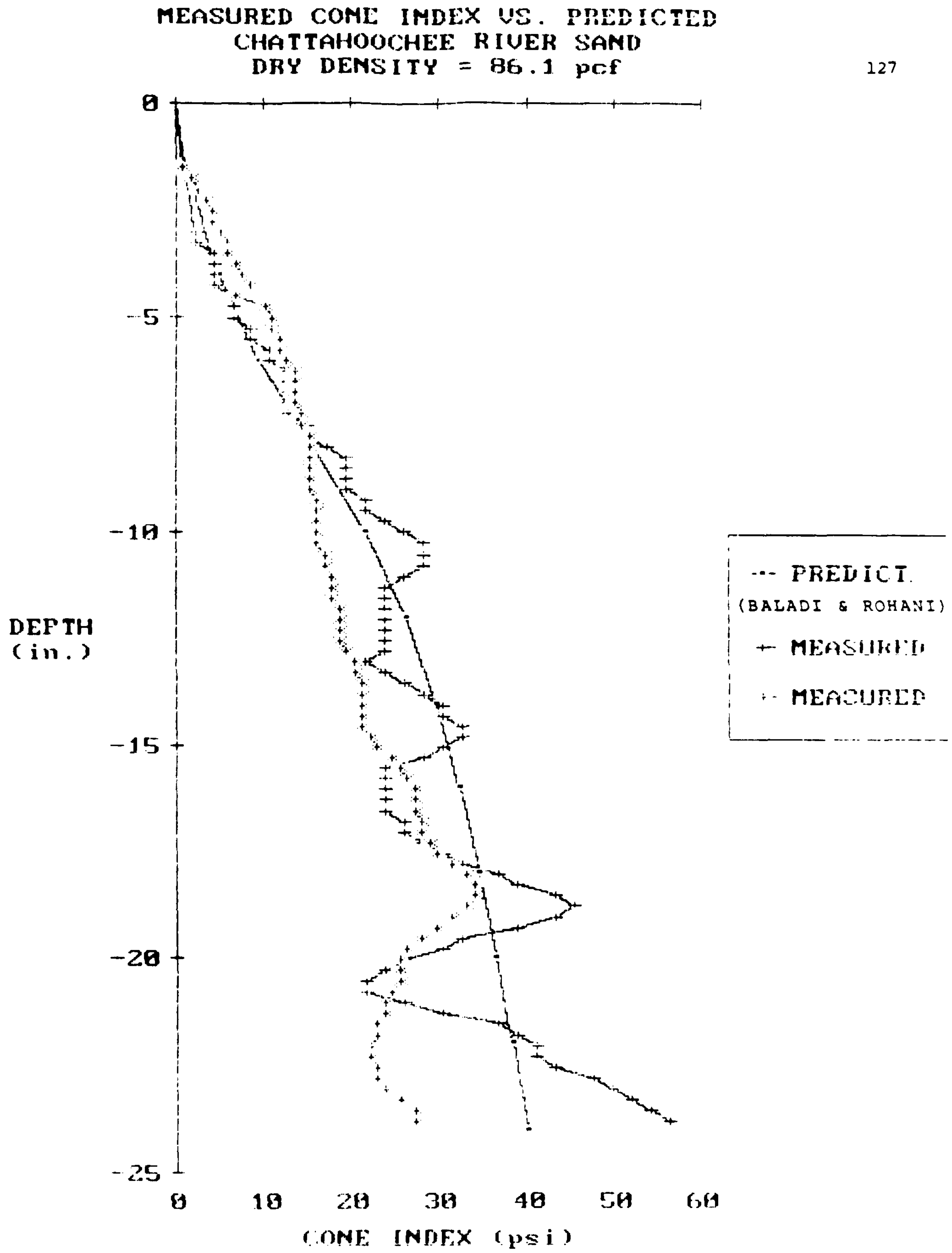


FIGURE 5-23 COMPARISON BETWEEN PREDICTED & ACTUAL CI

CHAPTER 6

FIELD TESTING PROGRAM

6.1 INTRODUCTION

Based on the analyses of the results presented in Chapter 5, the proposed automated military cone penetrometer system has been validated as a reliable tool to be utilized in measuring soil resistance in homogeneous samples. The fact that this proposed system has proficiently demonstrated its ability to provide reliable and repeatable results now allows the system to be analyzed on its ability to provide soil resistance data within a variable soil mass. Furthermore, the ultimate requirement of the cone penetrometer is to perform effectively and efficiently in a field environment where soil variability is commonplace. Specifically, variable, non-homogeneous soil conditions provide the foundation upon which nearly all off-road military mobility operations are conducted; therefore, trafficability studies, which require the use of the military cone penetrometer, must be able to accurately identify mobility cone index values in such conditions. This chapter will present the concept, design, and analyses of results of a small scale field testing program established to analyze the ability of the automated military cone penetrometer to provide reliable soil resistance data within a realistic, non-homogeneous soil mass.

6.2 CONCEPT OF THE FIELD TESTING PROGRAM

The broad objective in this field testing program is to qualitatively and quantitatively analyze the ability of the proposed system to effectively and efficiently collect reliable data within a non-homogeneous soil mass. The specific scope of the program is broken into two facets:

(1) To evaluate the capabilities of the proposed system in identifying the variability of soil resistance with depth in a realistic layered soil system.

(2) To evaluate the proposed system's ability to effectively measure the in-situ and remolding cone index values of a soil.

Ideally, a laboratory testing program utilizing non-uniform soil conditions in a calibration chamber would have provided the optimal means of accomplishing this scope. However, the lack of an adequate testing chamber and insufficient time and funds for its development precluded this approach to testing. As an alternate, a small scale field testing program was designed and implemented utilizing a soil which provided reasonable control

and thus allow at least a qualitative assessment of the automated military cone penetrometer operating in a variable soil environment.

The cornerstone in the concept of this testing program deals with the need to establish field conditions which simulate, as closely as possible, conditions that the automated system would possibly encounter in actual military trafficability applications. Based on conversations with the personnel in the Mobility Systems Division of the Waterways Experiment Station and on personal military experience, the hard over soft soil condition is one of the most important and difficult to quantitatively identify in military trafficability studies. Insufficient information for such conditions; i.e. depth of the hard layer, strength of the hard layer, strength of the underlying soft layer, and the extent of a soil's change in strength characteristics under loading conditions; may foster a false sense of security from a mobility aspect. Therefore, the concept of this program centers around the need to establish such a variable soil condition and to evaluate the automated military cone penetrometer's ability to effectively identify the hard over soft soil condition as well as changes in soil resistance which occur within a variable soil mass over time.

6.3 THE TESTING SOIL AND SAMPLE PREPARATION

A primary concern in military trafficability studies is to

effectively and efficiently identify the strength properties of those underlying soft soil layers. As previously noted, those soils which tend to mask their actual strength by forming a hard, stiff layer over an extremely soft layer of soil are especially important for military maneuver operations. In addition, it may be necessary to identify the extent of strength change with depth which these soils demonstrate due to daily weather conditions, particularly after periods of heavy rainfall.

A number of site/soil conditions were considered in order to complete the field study. These included backwater deposits along the Chattahoochee River, reclaimed spoil stockpiles from kaolin mining, and a laboratory prepared deposit in a large test pit in the geotechnical testing laboratory at Georgia Tech. The time and expense of these efforts precluded their serious consideration after this initial development phase. Fortunately, conditions at a nearby quarry offered a viable alternative. During the crushing, screening, and washing of stone aggregate at the granite quarry, large volumes of fine sand to silt sized, water laden pond screening material are wasted and stockpiled. A typical wasting pit was selected for the creation of a realistic soil test sample.

Based on the summary of works presented by Hall,1985; the experience of Dr. Robert C. Bachus, Asst. Professor at Georgia Tech; and from personal observation; the composition of a pond screening soil deposit is such that it tends to exhibit an increase in strength as it dries and provides a desiccated crust

of varying thickness with time. Improvement of properties can vary from a few hours to a few weeks. In addition, the soil exhibits a strong tendency to weaken when subjected to repeated loading conditions. Thus, pond screening seemed an ideal material for the cone penetrometer study. The actual pond screening material used in this testing program were from the Vulcan granite quarry in Kennesaw, Georgia; these deposits exhibit a high moisture content and fineness. The gradation characteristics of pond screening at Vulcan resemble fine sand as shown in Figure 6-1.

The samples created from these pond screenings were prepared at the quarry site in Kennesaw in a test pit approximately eight feet wide, 15 feet long, and three feet deep. Under the supervision of Vulcan personnel, the pit was constructed within a previously deposited and dried pond screening deposit by a bulldozer; the water laden test pond screenings were then placed in the pit by a dump truck. During placement, the pond screenings flow with ease from the dump truck as the particles are in nearly total liquid suspension. Therefore, in its initially prepared state, the properly constructed sample is unable to fully support the weight of a common person. As time passes, the water in the soil slowly permeates out of the sample, and the soil's strength tends to increase within the pit.

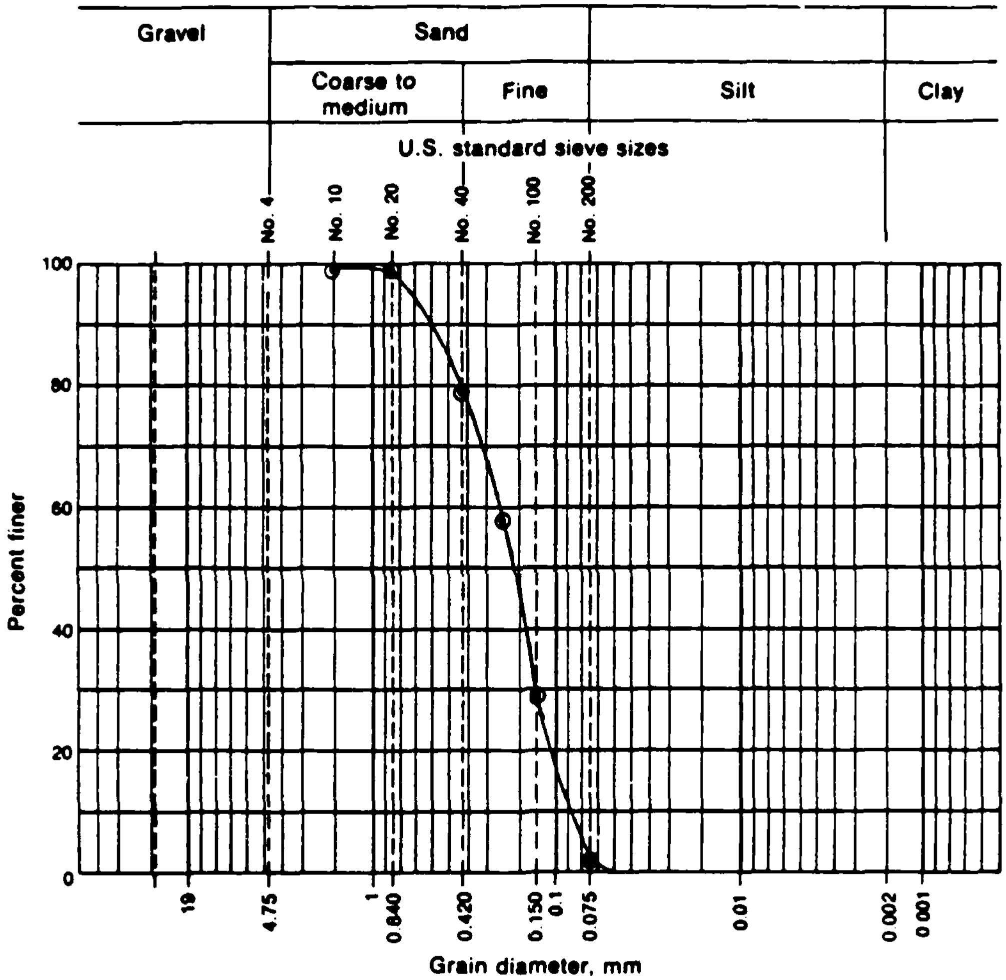


FIGURE 6-1 Grain-Size Distribution for Pond Screenings

6.4 TESTING SEQUENCE AND RATIONALE

Initially, one test sample pit was constructed for the collection of the cone penetration data needed to accomplish the goals within the concept of the field testing program. Testing within the pit was to be scheduled to allow measurement of the strength increase with depth over time. Additionally, remolded samples of the soil were prepared and tested during each scheduled visit to the quarry. Between the fifth and sixth week of the testing program, the heavy equipment operators at the quarry accidentally destroyed the initial testing pit. A second test pit and sample were constructed in the exact location of the initial pit to provide additional data for analyses.

A series of cone penetrations using the .5 sq.in. right circular cone were conducted in each of the two testing pits. A given test series consists of several cone penetrations which were conducted within the testing pit on a given date, thus establishing the time period which had elapsed since the date the testing pit was first constructed. Subsequent reduction and comparison of all test series data allows evaluation of the proposed system capabilities. Specifically, qualitative data reduction addressed the following two instrument related issues:

(1) The ability of the device to measure (a) the variability in soil resistance, (b) the expected increase in soil resistance over time, and (c) the

effects and sensitivity of soil and penetrometer to remolding.

(2) The ability of the device to effectively identify the extent and stiffness of the desiccated hard layer overlying the soft layer of soil.

Four series of test penetrations over a 4 week time period were conducted in the first test pit while two series over a 3.5 week time period were conducted in the second test pit.

Within each series on a given date, the automated military cone penetrometer was utilized to provide data for both the in-situ and remolded resistances of the soil. For reference within this study, the in-situ resistance of the soil is the resistance measured before the soil is subjected to any outside loading condition. The remolded resistance of the soil corresponds to the soil's resistance to the penetrating cone following a loading sequence by which the test location is subjected to 10 repetitions of dropping a 10 pound weight from a height of approximately 24 inches. In a prototype field loading condition, the subject site would be subjected to a repeated application of load due to mobilization of vehicles/troops across the site. Therefore, the response of the soil to application of a single load (cone penetration) may not be sufficient to evaluate the material's performance to repeated loading. The researcher proposes that these repeated drops of a weight simulate, to some

degree, the effect that repeated vehicle loadings would have upon a given soil mass. Therefore, this remolding of the soil sample provides a means to analyze the automated military cone penetrometer's capability of providing effective data on the effects that repeated military vehicle loadings may have on soil resistance.

The summaries of the cone penetration tests conducted within the four series in test pit one and the two series in test pit two are presented in Tables 6-1 and 6-2, respectively. These tables present the penetration test number, date of penetration, the location of penetration within the pit, and whether the data was collected from the in-situ or remolded soil. The penetrations among the testing series were conducted in either the center or side of the pit, therefore allowing a better basis for comparison of data between series. These series and test numbers will later be referred to in the discussion of test results. Several penetrations in the series of tests indicated the presence of rocks during the conduct of a penetration. These are noted as such in the Tables and not used for comparison purposes.

Penetrations of the pond screening sample in Test Pit #1 were not initiated until 1.5 weeks following the pit's construction because the strength of the sample was not sufficient to adequately support the weight of the researcher until that time. Subsequent series of cone penetrations at the center and side of the pit were performed at the 2, 3, and 4 week

TABLE 6-1 SUMMARY OF FIELD TEST DATA

TEST PIT #1

SERIES	TEST #	DATE	LOCATION	IN-SITU	REMOLDED
1	1-1	29 SEPT '87	CENTER	X	
1	1-2	"	CENTER	X	
1	1-3	"	CENTER		X (ROCKS)
1	1-4	"	SIDE	X	
1	1-5	"	SIDE		X
1	1-6	"	SIDE	X (ROCKS)	
1	1-7	"	CENTER		X
1	1-8	"	CENTER		X
2	2-1	2 OCT '87	SIDE	X	
2	2-2	"	CENTER	X	
2	2-3	"	CENTER		X
2	2-4	"	SIDE		X
3	3-1	9 OCT '87	SIDE	X	
3	3-2	"	CENTER	X	
3	3-3	"	SIDE		X
3	3-4	"	CENTER		X
4	4-1	16 OCT '87	SIDE	X (ROCKS)	
4	4-2	"	CENTER	X	
4	4-3	"	SIDE	X	
4	4-4	"	SIDE		X
4	4-5	"	CENTER		X

TABLE 6-2 SUMMARY OF FIELD TEST DATA

TEST PIT #2

SERIES	TEST #	DATE	LOCATION	IN-SITU	REMOLDED
1	1-1	20 NOV '87	SIDE	X	
1	1-2	"	CENTER	X	
1	1-3	"	SIDE	X	
1	1-4	"	SIDE		X
1	1-5	"	CENTER		X
1	1-6	"	CENTER	X (ROCKS)	
2	2-1	14 DEC '87	SIDE	X	
2	2-2	"	CENTER	X (ROCKS)	
2	2-3	"	CENTER		X
2	2-4	"	SIDE		X
2	2-5	"	CENTER	X (DATA LOST)	

time frames. However, the strength of Test Pit #2 was sufficient to allow the initiation of penetrations approximately three days following this pit's construction. The soil used in the construction of both pits came from the same source, and the weather conditions, for all practical purposes, were the same during the construction and prior to the initial penetrations for each of the pits. The rapid strength gain exhibited by Test Pit #2 will be further discussed in the analyses of results.

6.5 DISCUSSION AND ANALYSES OF THE TESTING RESULTS

This section will present a thorough discussion concerning: (a) the consistency variation with depth over time within the sample, (b) the extent and stiffness of the desiccated crust, (c) the variance in strength between the two test pits, (d) the effects of repeated loading/remolding.

Within the discussion of each of these facets, analyses of the cone penetration data collected in the testing program as well as conclusions based on these analyses will be presented. It should be noted that, since the automated military cone penetrometer has proven its ability to provide repeatable and reliable results in the laboratory validation testing program, the cone index values collected in the field testing program will be accepted as accurate. Therefore, the discussion which follows will concentrate totally on the capability of the automated system to effectively accomplish the above aspects.

As previously noted in Chapter 2, military trafficability studies are primarily concerned with the strength properties of the soil within the top two feet of a soil mass. Generally, soil as a whole is considered to be variable in nature and the actual strength properties it exhibits close to the surface at a given time are many times highly dependent upon the prevailing weather conditions in the area. The proper identification of strength properties of a given soil mass within two feet of the surface could prove to be the difference between success and failure in military mobility operations conducted on non-paved surfaces.

Since the primary tool used in trafficability studies to identify the strength of a soil is the conventional military cone penetrometer, then the need for the penetrometer to provide accurate and precise data is paramount. Thus, the requirement is established for evaluating the ability of the automated military cone penetrometer to effectively identify the variability of soil resistance with depth in a realistic layered soil system. The following subsections will present plots and provide a discussion of the results obtained from Test Pit #1 concerning variability and qualitative property evaluation. It is noted at the onset that the results of the data collected in these series of penetrations demonstrate that the soil resistance within the test samples on a given date is variable in depth as well as in location within the test pit. This point is considered a natural occurrence in penetration testing and detailed analysis is considered beyond the scope of this initial study. In addition,

plots of the results comparing the center and side penetrations within a given series as well as any other plots of field test penetration data not presented in this chapter are located in Appendix C for further reference.

6.5.1 VARIATIONS IN SOIL RESISTANCE WITH DEPTH OVER TIME

The permeation of the pore fluid from the sample and the prevailing weather conditions at the testing site are considered to be the primary factors responsible for changes in soil resistance in the pond screenings test pits. The ability of the automated military cone penetrometer to properly recognize and quantify the magnitude of the soil resistance changes due to these factors over time will be the primary concern for this discussion.

During the conduct of the penetration tests in Test Pit #1, the pond screenings did not experience any measurable precipitation and was subjected to normal autumn temperatures for the Atlanta area. In general, the results of the data collected from the automated military cone penetrometer tests conducted in Test Pit #1 (Test Series 1 through 4) demonstrate that the soil resistance at a given depth in this test sample tends to increase from one series to the next. From the discussion on the selection of the test soil, a pond screenings deposit would be expected to exhibit such an increase in strength over time due to the dissipation of pore water within the soil mass.

Continuous profile plots of the collected data which graphically depict this increase in strength among the four series of tests are presented in Figures 6-2 and 6-3 for penetrations conducted at the center and side locations, respectively. Two key observations are immediately noted: (1) the automated cone is effective in delineating small variations in consistency with depth and (2) there is a dramatic effect of cone index variation over time in the test pit. The data collection process and sensitivity of the automated military cone penetrometer allows a range from less than 10 psi to greater than 250 psi in soil resistance values to be effectively captured. This extreme range in data depicts the volatile nature of soil resistance within the pond screening sample. The detail provided in the data collection process of the automated military cone penetrometer potentially allows more specific analyses of this soil's strength characteristics.

Specifically, these plots demonstrate that there seems to be a relatively large increase in soil resistance between the second and third weeks (Test series 2 and 3, respectively) following the test pit's construction. A possible reason for such a noticeable increase could be directly related to the fact that numerous shrinkage cracks, varying in width from .5 to 2 inches, appeared throughout the testing sample between test series 2 and 3. These cracks potentially provided an additional, and possibly easier, means for the dissipation of the pore water in the soil, therefore increasing the resistance capability of the soil.

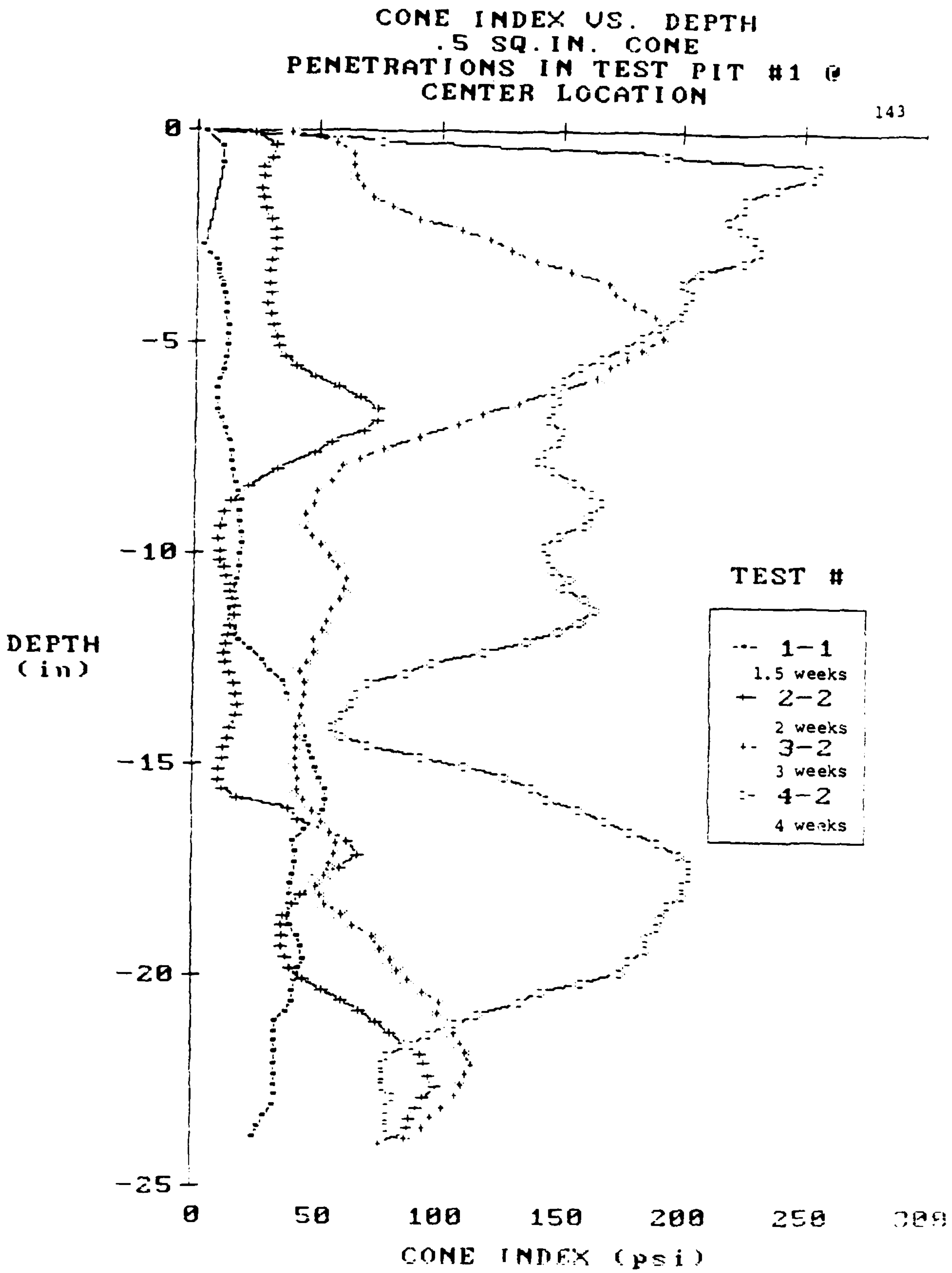

CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
PENETRATIONS IN TEST PIT #1 @
CENTER LOCATION
143
DEPTH
(in)
0
-5
-10
-15
-20
-25
0
50
100
150
200
250
300
CONE INDEX (psi)
TEST #
1-1
1.5 weeks
2-2
2 weeks
3-2
3 weeks
4-2
4 weeks

FIGURE 6-2

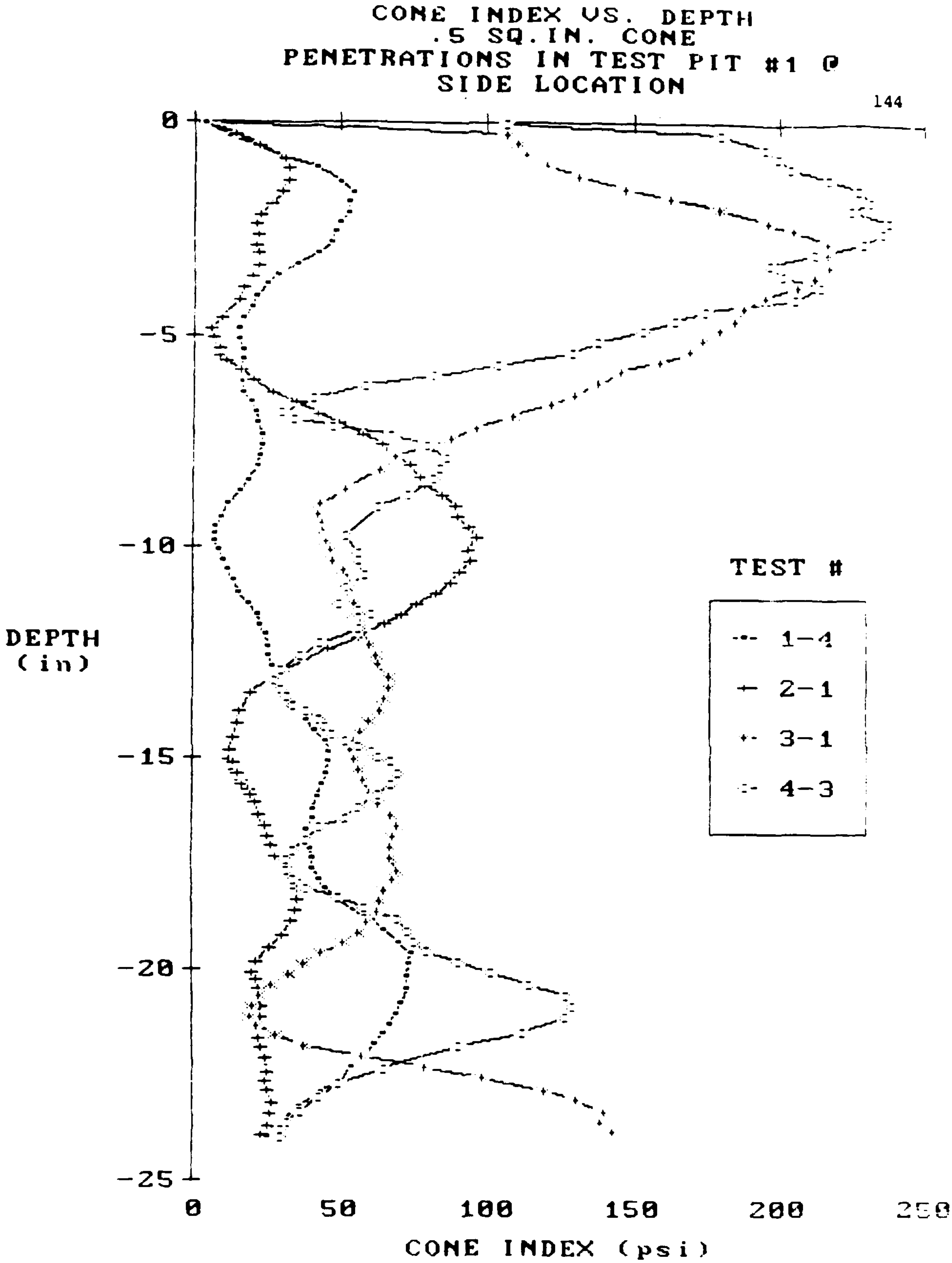

CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
PENETRATIONS IN TEST PIT #1 @
SIDE LOCATION
0
-5
-10
-15
-20
-25
DEPTH
(in)
0
50
100
150
200
250
CONE INDEX (psi)
TEST #
1-4
2-1
3-1
4-3

FIGURE 6-3

In addition, these plots show that the upper 6 to 10 inches of the pond screenings generally demonstrate a tendency to increase strength much more rapidly than the lower segments of the test sample. The reason for this increase is again considered to be related to the dissipation of pore fluid. The dissipation of the pore fluid in the fine pond screenings sample is easily accomplished in the upper layers of the sample through the mechanism of evaporation and thus formation of a desiccated crust.

The above observations establish that the proposed automated military cone penetrometer system is fully capable of effectively identifying the variance in soil resistance within a highly volatile soil mass over an extended time period. In addition, the sensitivity of the device and the large number of data points collected within a single cone penetration allows sufficient data for analysis.

6.5.2 IDENTIFYING THE EXTENT OF THE DESICCATED CRUST

From personal experience and conversations with mobility personnel at WES, the existence of a hard layer overlying a soft soil layer is considered to be one of the most important and most difficult soil conditions to quantitatively identify in military trafficability studies. One reason for this difficulty stems from the fact that the thickness of the desiccated crust is extremely variable in nature and, many times, dependent upon

prevailing weather conditions at the time a study is conducted. Therefore, if the automated system can be shown to effectively identify this condition, then it may prove to be extremely beneficial in future trafficability study requirements.

Referring again to Figures 6-2 and 6-3, the presence of a desiccated crust is obvious in the series of tests conducted during the third and fourth weeks in Test Pit #1 at both the center and side locations. The data collected from the cone penetration conducted at the side of the test pit during the fourth week, Test # 4-3 of Figure 6-3, is selected as the representative penetration which will be further analyzed to determine specific aspects of this hard over soft soil layering condition.

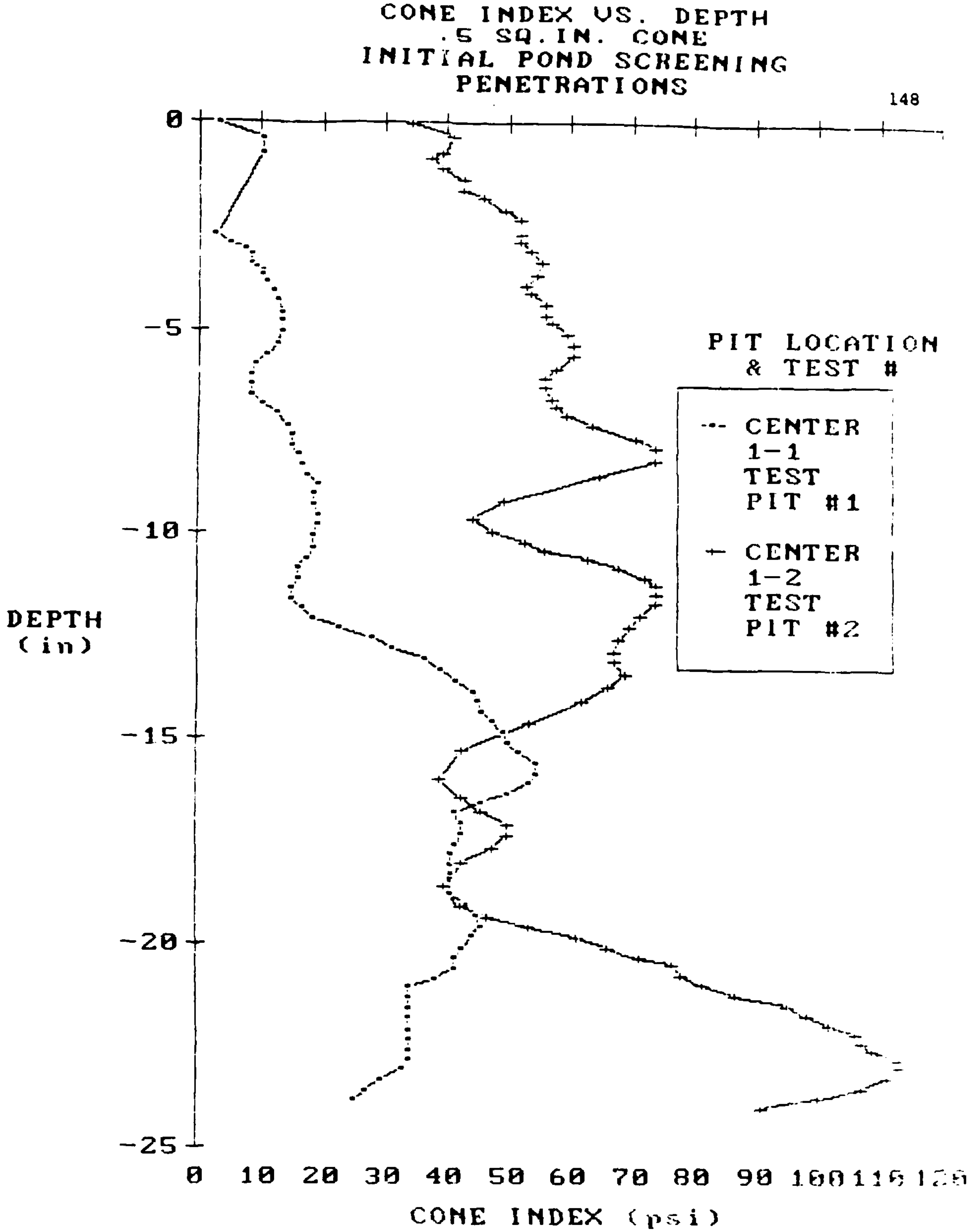
Test # 4-3 presents detailed data which allows clear delineation of the hard over soft layering condition. Specifically, the desiccated crust extends to a depth of approximately 7 inches below the surface of the test sample. At this 7 inch mark there appears to be a clear separation between the hard and soft layers. The hard, desiccated crust exhibits an average strength in the range of 160 to 200 psi. The soft layer seems to exhibit a nearly uniform average strength of 60 psi to a depth of 20 inches. Between the 20 and 22 inch marks, the soil resistance exhibits a dramatic, localized increase in strength before tailing off to a value of nearly 40 psi at a depth of 24 inches.

The results shown in Figures 6-2 and 6-3 as well as in many

of the other figures in this chapter and Appendix C clearly demonstrate the qualitative assessment capabilities of the automated military cone penetrometer. Because of the detail provided in the penetration data collected by the automated military cone penetrometer, a quantitative analysis of the sensitive hard over soft layered soil condition can be accomplished using theoretical procedures like those developed by Baladi and Rohani, 1981. It is noted that an assessment of the Baladi and Rohani theory was not pursued as a part of the scope of this current work. It is anticipated that this evaluation and analysis will be part of the next phase of this project. The presented data demonstrate that the automated military cone penetrometer is highly capable of providing the detailed, sensitive information for military trafficability studies in difficult soil conditions.

6.5.3 VARIANCE OF INITIAL STRENGTHS OF TEST PITS # 1 & 2

The initial in-situ data collected by the automated military cone penetrometer in both of the test pits are presented in Figures 6-4 and 6-5. Notice that the soil resistance achieved in three days in Test Pit # 2 is for all practical purposes equal to or greater than the strength demonstrated by the sample in Test Pit # 1 after 1.5 weeks. In addition, it is obvious that there are strikingly different trends between the side and center results of the two pits. At the center of the test pit, the



CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
INITIAL POND SCREENING
PENETRATIONS
DEPTH (in)
CONE INDEX (psi)
PIT LOCATION & TEST #
CENTER 1-1 TEST PIT #1
CENTER 1-2 TEST PIT #2

FIGURE 6-4

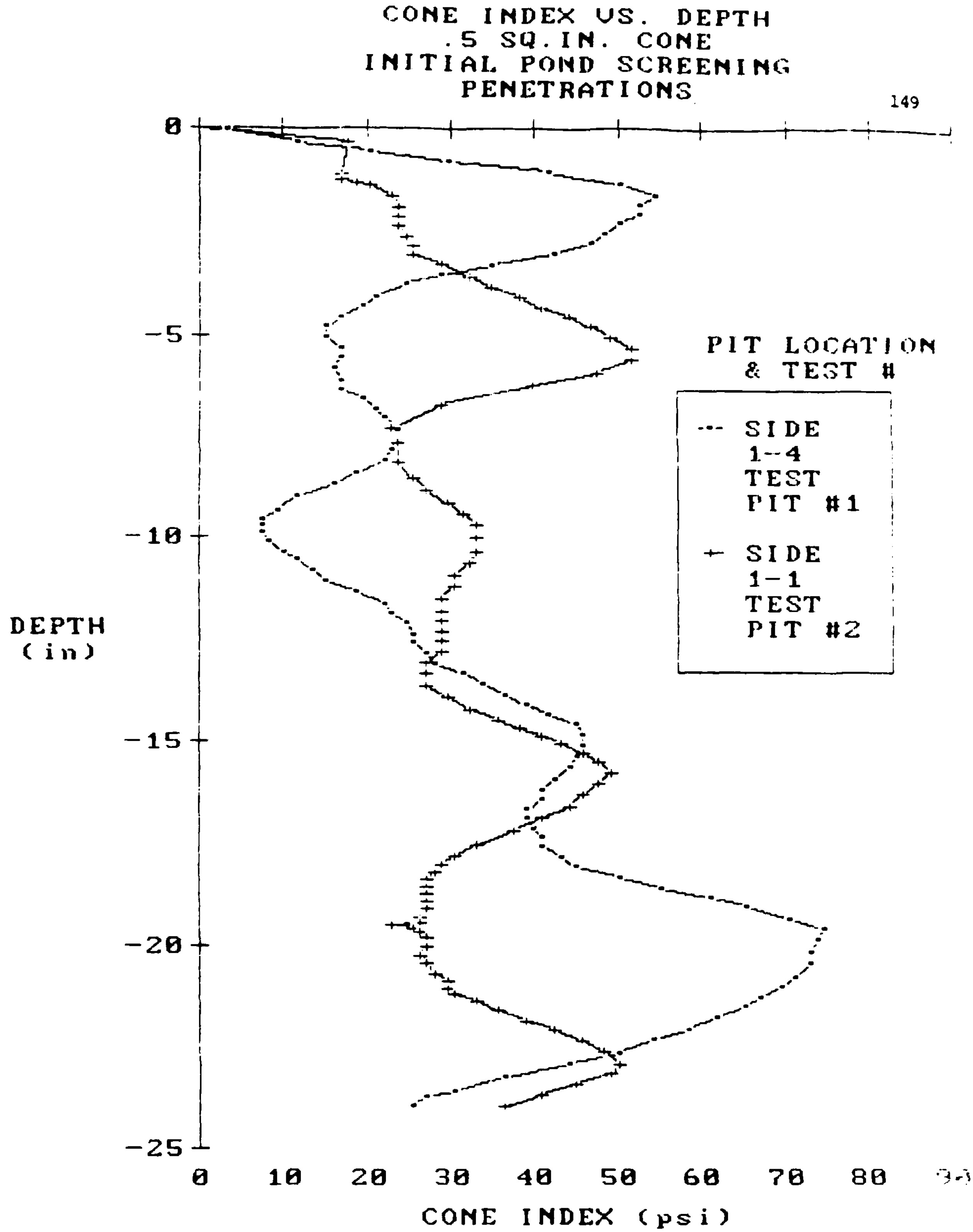

CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
INITIAL POND SCREENING
PENETRATIONS
DEPTH (in)
0
-5
-10
-15
-20
-25
0
10
20
30
40
50
60
70
80
CONE INDEX (psi)
PIT LOCATION & TEST #
SIDE 1-4 TEST PIT #1
SIDE 1-1 TEST PIT #2

FIGURE 6-5

penetration result from Test Pit # 2 is for all practical purposes consistently larger than that of pit # 1. At the side of the test pit, the penetration results of both pits are relatively equal. The reason for this trend is considered a function of drainage. Specifically, the center of Test Pit # 1 did not possess an adequate drainage path to allow the dissipation of pore fluid and therefore demonstrated less soil resistance.

All of the testing parameters (soil, weather conditions, test site, etc.) were initially considered to be identical for each of the constructed test pits. As the strength characteristics of the soil samples were not identical, based on the elapsed time between the dates when the pit was constructed and the initial penetrations were performed, this assumption was not reliable. Results of the cone penetrations indicate that the soil placed in Test Pit # 2 did not possess an initial moisture content as high as that in Test Pit # 1. Close personal inspection by the researcher supports this observation. Once again the automated military cone penetrometer is shown to provide valuable qualitative and quantitative data for assessment of local site conditions.

6.5.4 ABILITY TO IDENTIFY CHANGES DUE TO REPEATED LOADINGS

The ultimate goal of military trafficability studies is to establish the capability of a soil formation to sustain repeated

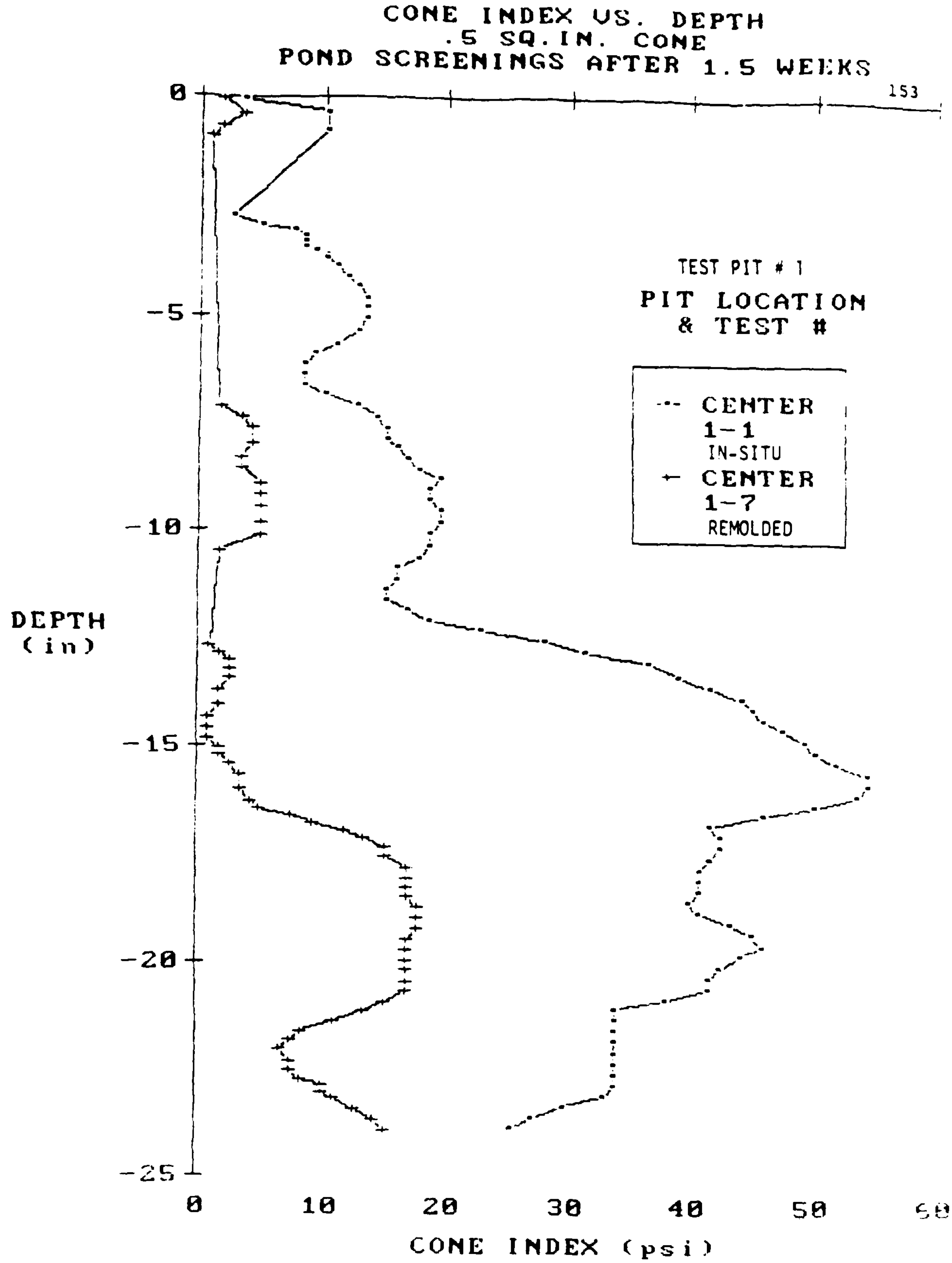
loadings of a certain number and class of military vehicles. Specifically, this goal is centered around the determination and comparison of critical cone index values to values needed for vehicle mobilization. As presented in Chapter 2, the military vehicle cone index and rating cone index values are compared to establish the final trafficability parameters of the soil mass under investigation.

In general, each class of military vehicle is assigned a vehicle cone index value which specifies the minimum soil resistance required of a soil mass to successfully support 50 passes of a particular vehicle. This value is compared to the soil's rating cone index value which is derived from multiplying the in-situ cone index by the remolding cone index value of the soil mass in question. The in-situ cone index value is determined from cone penetrations, conducted in the same manner as those performed in this field testing program, at the site under investigation. The remolding cone index value is determined from cone penetrations conducted in the field with a cylindrical test sample of the soil in question. A brief summary of the steps involved in determining the conventional remolding cone index value include: (1) obtaining an undisturbed soil test sample, (2) determining the in-situ cone index value of the soil sample, (3) remolding the sample by subjecting it to a sequence of repeated impact loadings, (4) determining the remolded cone index value of the soil sample, and (5) determining the remolding cone index value by dividing the remolded cone index value by the

in-situ cone index value of the test sample. A more thorough discussion of these steps is presented in Chapter 2.

The focus of discussion in this section will concern the aspect of determining the above referenced remolded cone index value of a soil. Specifically, the ability of the automated military cone penetrometer to effectively establish the effects of remolding on the pond screenings in Test Pit # 1 will be scrutinized. The subsequent paragraphs will present a discussion and analysis of the penetration data collected by the automated military cone penetrometer following the application of the repeated loading conditions previously discussed in section 5.4 on the pond screenings sample. Note that the remolding techniques developed for this project differ from the conventional technique referenced in TM 5-330. Because the proposed techniques do not require excavation of samples and test the soil in place, they are believed superior to conventional techniques. Verification of this conclusion requires further study.

Representative plots comparing the in-situ and remolded cone index values collected with the automated system at the center location of Test Pit # 1 in Test Series 1 through 4 are presented in Figures 6-6 through 6-9, respectively. Similar plots of data collected at the side location in Test Pit # 1 and the series of tests in Test Pit # 2 are located in Appendix C for further reference. All of these plots depict the general trend that the remolded cone index of the pond screening samples tends to be



CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 1.5 WEEKS
153
TEST PIT # 1
PIT LOCATION
& TEST #
CENTER
1-1
IN-SITU
CENTER
1-7
REMOLDED
DEPTH
(in)
0
-5
-10
-15
-20
-25
0
10
20
30
40
50
60
CONE INDEX (psi)

FIGURE 6-6

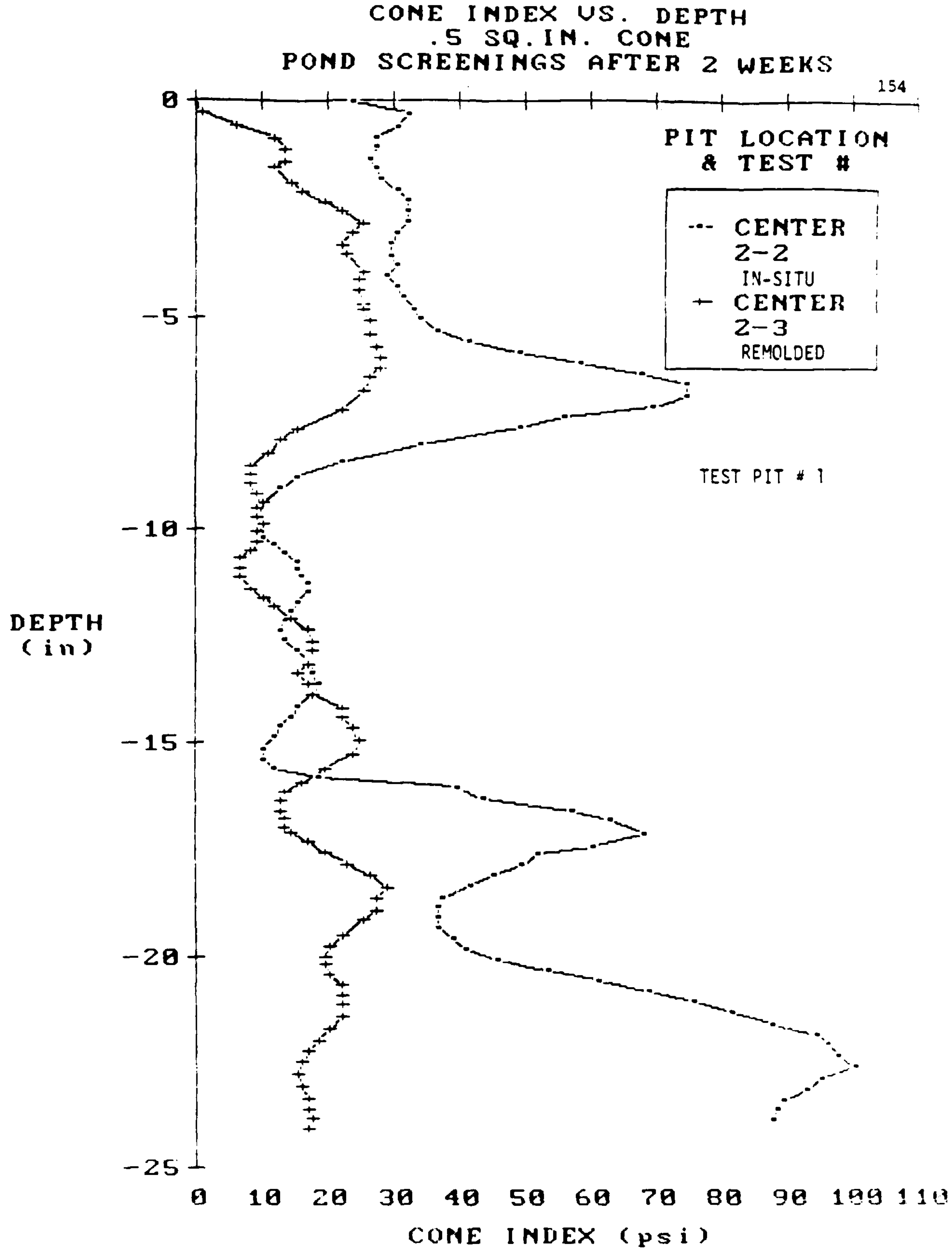

CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 2 WEEKS
PIT LOCATION
& TEST #
CENTER
2-2
IN-SITU
CENTER
2-3
REMOLDED
TEST PIT # 1
DEPTH
(in)
0
-5
-10
-15
-20
-25
0 10 20 30 40 50 60 70 80 90 100 110
CONE INDEX (psi)

FIGURE 6-7

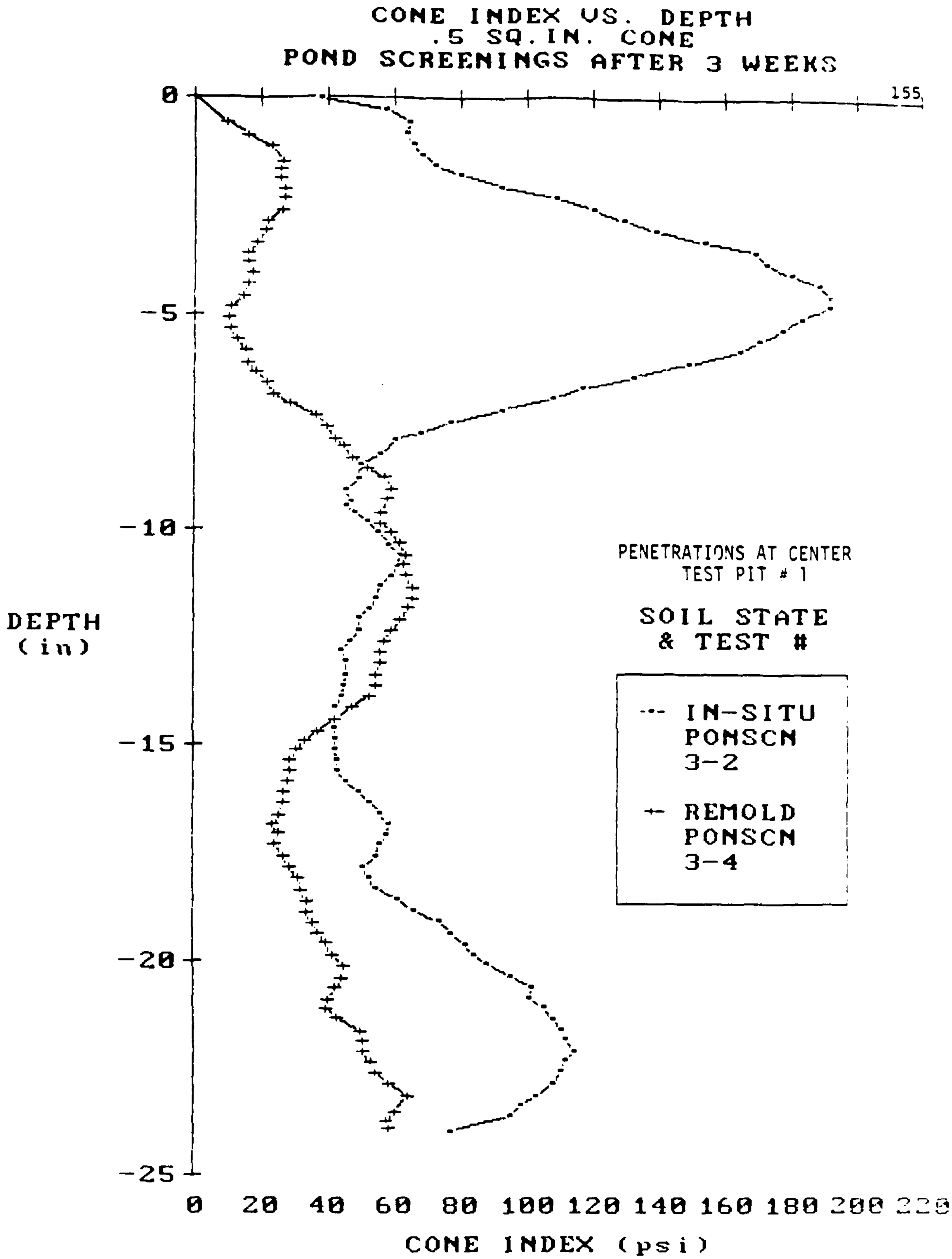

CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 3 WEEKS
155
0
-5
-10
-15
-20
-25
DEPTH
(in)
PENETRATIONS AT CENTER
TEST PIT # 1
SOIL STATE
& TEST #
IN-SITU
PONSCN
3-2
REMOLD
PONSCN
3-4
0 20 40 60 80 100 120 140 160 180 200 220
CONE INDEX (psi)

FIGURE 6-8

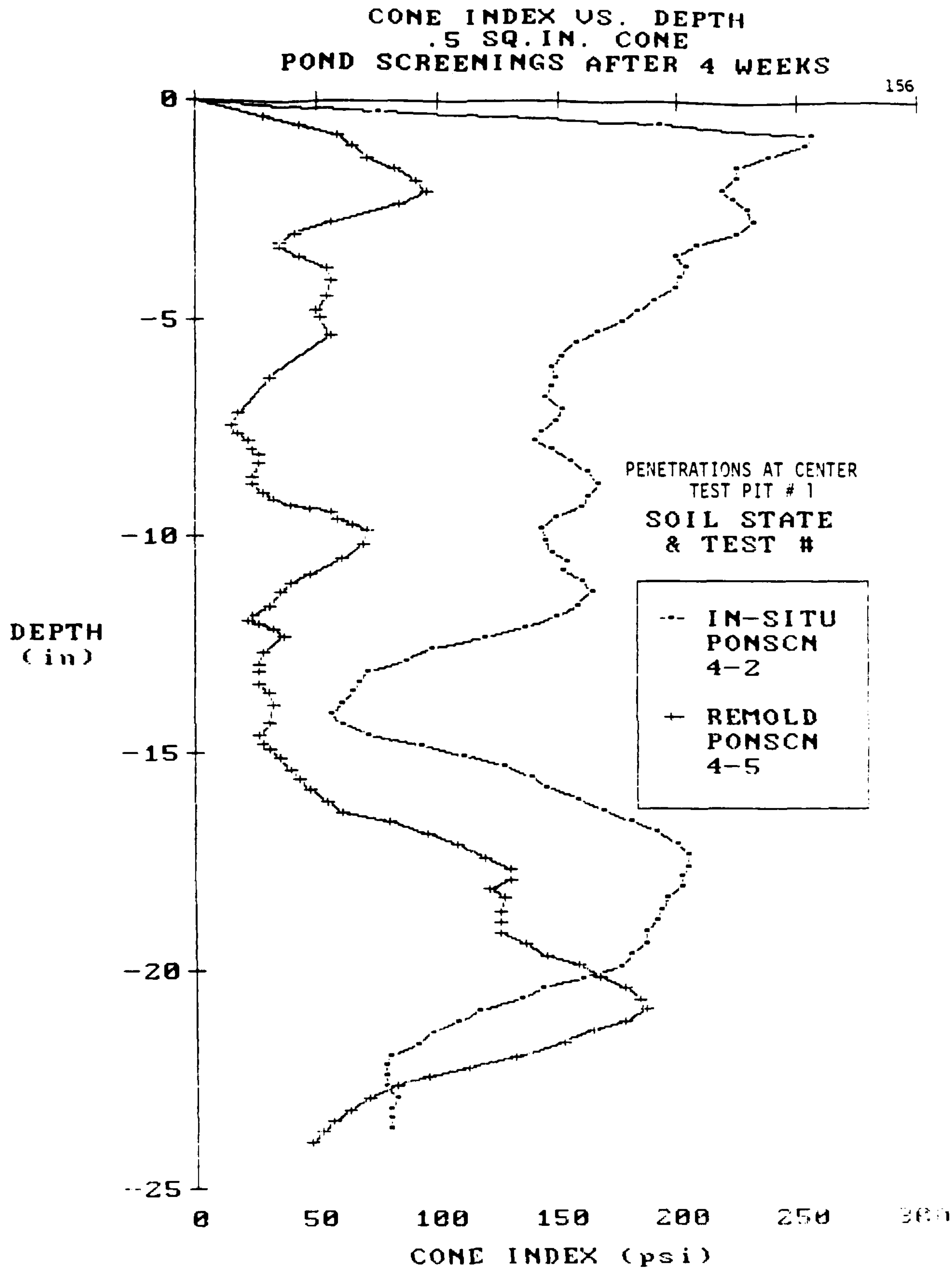

CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 4 WEEKS
156
DEPTH (in)
0
-5
-10
-15
-20
-25
0
50
100
150
200
250
300
CONE INDEX (psi)
PENETRATIONS AT CENTER
TEST PIT # 1
SOIL STATE & TEST #
IN-SITU PONSCN 4-2
REMOLD PONSCN 4-5

FIGURE 6-9

less than the in-situ cone index over the entire depth of penetration.

Possessing a high moisture content and fineness composition, the pond screenings sample in Test Pit # 1 would be expected to exhibit a decrease in strength when subjected to the repeated impact loading situation. The reason for this expected strength decrease is due to the fact that the applied loading condition should cause the pore pressure in the test sample to increase therefore decreasing the soil's effective stress. The penetration data collected by the automated military cone penetrometer in each of the four series of tests in Test Pit # 1 exhibits this expected behavior.

In addition, the magnitude of strength change depicted in Figures 6-8 and 6-9 demonstrates that an inadequate trafficability study in these soil conditions could possibly lead to puncture failure in subsequent military mobility operations. The basis for this conclusion is provided through further analysis of the penetration data for week 4, Figure 6-9. Based on this collected penetration data, the average in-situ cone index value is approximately 160 while the average remolded cone index value is approximately 50 over the 24 inch depth of interest. If only the in-situ cone penetration test had been conducted to satisfy a trafficability study, then the military unit requiring this information would have drawn false conclusions concerning the trafficability of this terrain. The unit would only be able to pass a relatively small number of

light wheeled vehicles over this soil mass before having extreme mobility difficulty.

The analysis in the preceding paragraph establishes the fact that the success of off-road military mobility operations in volatile soil conditions could prove extremely dependent upon the accurate collection and analyses of cone penetration data. The presentation of results in this section demonstrates that the automated military cone penetrometer is fully capable of providing the detailed, continuous data over the critical depth of interest needed to establish this accurate collection and analyses of soil resistance. Specifically, this section establishes the fact that the automated military cone penetrometer can successfully identify changes between the in-situ and remolded cone index values required in military trafficability studies under extremely variable soil conditions.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 INTRODUCTION

The conventional proving ring cone penetrometer system currently used by the military to measure soil resistance during the conduct of trafficability studies is possibly out of date with current technology in the engineering field of in-situ testing. One must question the efficiency and accuracy of a system which requires that soil resistance and depth of penetration data be manually read from a proving ring dial while depth of penetration is estimated from notches on the cone rod. The speed must similarly be questioned when these data must be manually recorded, particularly in light of the extensive advancements in computer and electronic technology in the past 10 years. Such an antiquated system could prove to be a hinderance on the modern battlefield where the military force that is able to quickly and effectively access information about the theater of operations will have a definite advantage.

The automated cone penetrometer developed in the conduct of this research establishes a very strong foundation for the development of a system which will provide the U. S. Armed Forces with such an advantage. The laboratory and field testing results

presented in this research demonstrate the designed automated system's ability to detect and record reliable soil resistance and depth of penetration data in an extremely effective and efficient manner. The following section will present certain conclusions which resulted from the laboratory and field testing programs of the automated military cone penetrometer in the conduct of this research. Following the presentation of the testing conclusions, specific advantages and disadvantages of the automated system compared to the conventional proving ring system will be presented. The chapter will then conclude with suggested recommendations for equipment modifications and further research concerning the automated military cone penetrometer and its use in the conduct of trafficability studies.

7.2 LABORATORY AND FIELD TESTING CONCLUSIONS

In general, the laboratory and field testing programs conducted in this research conclusively demonstrate that the automated cone penetrometer is fully capable of meeting the current operational demands established for military cone penetrometer testing. The basis for this general conclusion is founded on the following specific conclusions concerning the results of these testing programs.

7.2.1 Reliable Results

In the conduct of the laboratory testing program, the automated military cone penetrometer successfully demonstrated that it could measure soil resistance and depth of penetration data in an extremely reliable and repeatable fashion. Specifically, the device successfully duplicated the accredited work by Vesic (1963) whereby a direct relationship between the dry density of Chattahoochee River Sand and soil resistance as measured by a penetrating cone was established. Based on the reliability of the results from this phase of the testing program, the apparatus was then considered applicable for analyzing the effects of cone size, rate of penetration, and concentrated surface loading conditions on the value of cone resistance.

7.2.2 Effect of Cone Size

The effect of cone size on measured soil resistance was analyzed in the laboratory testing program by using .5 and .799 inch diameter 30 degree right circular cones attached to a 3/8 inch diameter steel shaft to conduct cone penetration tests on various densities of Chattahoochee River Sand. The results of penetration tests conducted on loose sand samples are consistent with results expected from a bearing capacity analysis with the .799 inch cone exhibiting larger values of soil resistance.

However, the results for the penetration tests with cone diameter (Dc) to shaft diameter (d_s) ratios (Dc/d_s) equal to one (.5 inch diameter cone) in the dense samples demonstrate higher soil resistance values which is attributed to the lack of space allowed for dilation to occur during penetration. Thus, the automated cone penetrometer provides a tool which is sensitive enough to detect subtle variations and allow a fundamental investigation of the failure mechanism.

7.2.3 Rate of Penetration

Based on the cone penetration data collected, it is concluded that rates of penetration ranging between 4 and 8 inches per minute (factor of 2) have no significant effect on the measured cone index value for "dry" Chattahoochee River Sand. It is proposed that one may not be able to draw a similar conclusion if the magnitude of change in the rate of penetration were possibly increased to a factor of 10 or if the sand were saturated as has been shown by Campanella and Robertson (1982) in their research at the University of British Columbia and others on the conventional CPT. This aspect provides a basis for further research to be discussed in the final section of this chapter.

7.2.4 Concentrated Surface Load Effects

The laboratory test data conclusively demonstrates that the weight of the operator during the conduct of cone penetration testing establishes a concentrated surface load which directly influences the measured value of soil resistance in dry Chattahoochee River Sand samples. Specifically, these results show that as the weight of the operator increases so does the value of measured soil resistance at a corresponding depth for a given density of dry sand. This increase tends to be much more profound in the loose sand. The placement of the operator's feet on the foot pads of the base plate causes an increase in confinement, vertical stress, and lateral stress which in essence means that the penetrating cone will measure higher soil resistance values than are actually present in the in-situ condition. This effect is undoubtedly common to the conventional system and these data indicate that the historical data base is biased to the weight of the operator and the position of the operator's feet during testing. This effect should be further studied for other soils and accounted for in a standard fashion in future trafficability investigations.

7.2.5 Comparison to WES Analytical Model

An in-depth study to analyze the WES analytical model was not within the original scope of this initial testing phase for

the automated military cone penetrometer. However, a quick application of this model to predict the soil resistance of Chattahoochee River Sand over a 24 inch depth of cone penetration was conducted and the results compared to measured soil resistance values. The results of this comparison demonstrate that the model is undoubtedly promising. This model is useful for evaluating soil properties and not just for trafficability purposes; therefore, it shows in sight potential. The sensitivity demonstrated by the automated cone penetrometer system makes it an ideal tool for further studies of this model.

7.2.6 Measuring Soil Variability

During the conduct of the field testing program, the automated military cone penetrometer successfully demonstrated its capability to effectively measure variability in a soil mass with extreme detail over a 24 inch total depth of penetration. In general, the device effectively quantified the magnitude of change in the strength of the pond screenings presumably as a result of the dissipation of pore pressures over time. In addition, the sensitivity of this device enabled it to identify the detailed soil resistance and corresponding depth of a variably stiff desiccated crust overlying an extremely soft layer.

7.2.7 Vehicle-Soil Relationship

The automated military cone penetrometer demonstrated that it is an excellent tool in establishing the strength loss caused by repeated loading. It is proposed that this device can augment the overall aspect of military trafficability studies by providing a more efficient and effective means of establishing the effects of vehicle loading on given soil conditions.

In addition, the military's procedure of establishing the remolded strength of a soil by measuring soil resistance in a 2 inch diameter steel cylinder is questionable based on the results of this research and work performed by Parkin and Lunne (1980). These results suggest that boundary effects may bias these remolded strengths and thus the rating cone index of a soil. The automated military cone penetrometer is considered an ideal tool to further analyze this aspect.

7.3 ADVANTAGES OF THE AUTOMATED CONE PENETROMETER

As stated throughout this report, the automated military cone penetrometer has successfully demonstrated that it is fully capable of performing the functions required in the conduct of military cone penetration tests. The success of the automated system establishes the fact that such a system is considered feasible and will provide specific advantages not realized with the current proving ring system. The following sub-sections will

discuss the specific advantages realized with the automated system as presented in this report.

7.3.1 Automated Data Acquisition

The major advantage of the automated system concerns the manner in which the soil resistance and depth of penetration data are recorded. In general, the automated data acquisition system proved that it could efficiently and effectively measure and record the soil resistance and corresponding depth of penetration in both homogeneous and non-homogeneous soil conditions. The fact that all of the data is obtained automatically on relatively small, field-capable instrumentation reduces the possibility of data being incorrectly recorded; this appeared to be a major source of error associated with the proving ring system. In all of the tests conducted in this research, the automated data acquisition system continually recorded reliable and repeatable results of the existing soil conditions.

7.3.2 Efficiency of Overall Operation

The handling and operation of the automated cone penetrometer only requires the attention of one operator. The design of this system eliminates the need for both an operator and assistant as suggested for facilitating the operation of the proving ring system. In specific, TM 5-330 suggests an assistant

be used in the proving ring system to reduce the possibility of error and the amount of time required in the task of manually recording data. By providing a more efficient system, the automated system decreases both the possibility of error and the time required to record cone penetration.

As designed, the automated system allows a single operator to conduct numerous cone penetration tests within a very short time period. Once the operator has conducted the desired penetrations, the device can be directly attached to a portable or office-based computer for data reduction, storage, plotting, and analysis. As noted in the context of this report, the number of penetration tests which can be effectively retrieved by a single operator in a single testing session with the automated cone penetrometer is currently limited only by the computer software available for analysis. In this first generation system, this is approximately 5 tests when utilizing the LOTUS electronic spreadsheet program for data reduction and analyses.

The established design allows cone penetration data to be saved in the data logger for as long as required; therefore, the operator is not required to transport a computer during the conduct of these penetration tests. This means that the analyses of soil resistance based on the automated cone penetration test results can be conducted in a totally separate location at a later time. Thus, the whole sequence of operation concerning the automated military cone penetrometer seems to provide the military with a much more efficient means of obtaining soil

resistance data with a manpower requirement of only one soldier.

7.3.3 Sensitivity

In both the field and laboratory testing programs, the automated cone penetrometer proved that it could provide detailed qualitative soil resistance data at a corresponding depth. The automated system demonstrated a capability in which a change in soil resistance or cone index of .852 psi can be accurately measured using the .5 square inch cone. Such sensitivity would only be possible through interpolation when using the proving ring cone penetrometer. For this study the depth sensitivity for each data point was approximately Ø.25 inches. If additional data points are required, depth sensitivity of approximately .Ø25 inches could easily be achieved by software control.

This increase in sensitivity, relative to the conventional proving ring cone system, augments the military's ability to better define the soil-vehicle relationships which are the cornerstone in the conduct of trafficability studies. As previously noted, this ability was successfully demonstrated in the field testing program where the automated system was able to effectively establish the magnitude of change in soil resistance due to repeated loading conditions.

The sensitivity of this device also provided an effective means for studying the effects of penetration rate, cone size, and concentrated surface loading conditions on soil resistance.

The sensitivity features and the small size of the device provide an excellent resource for conducting further research in a laboratory environment.

7.3.4 Soil Profiling

The beauty of the automated cone penetrometer system is the fact that this system provides approximately 96 data points over a 24 inch depth to establish a nearly continuous soil profile; more data point can easily be collected via software control. As presented throughout this report, the automated system enables these data points to be electronically communicated through a computer to a spreadsheet program where the data can then be easily transposed into a hard copy soil profile. In specific, the automated system provides an efficient means to precisely detail a soil profile which can then be quickly and efficiently analyzed to establish the key aspects of soil resistance as it is related to military trafficability studies.

The automatic soil profiling also allows a more critical analysis of a soil's cone index value than is currently provided with the proving ring system. This conclusion is based on the fact that over a depth of 24 inches the automated system provides approximately 96 data points while the proving ring system would realistically allow approximately four cone index values to be manually recorded. Using the time consuming recommendation by Baladi and Rohani (1981), approximately 24 data points would be

manually recorded.

7.4 DISADVANTAGES OF THE AUTOMATED CONE PENETROMETER

Even though the automated military cone penetrometer has successfully demonstrated its capabilities and use in military applications is considered feasible, the change from a manual to an automated system does establish specific disadvantages which must be considered.

7.4.1 Training

Switching to an automated system will establish the need to develop a new training procedure for the conduct of cone penetration testing. Encompassed in this requirement will be the need to retrain the current operator's of the military cone penetrometer. The Operator's Manual presented in Appendix A establishes an excellent foundation which would facilitate this requirement. Even though the automated system may require an initial influx of training requirements, such a system will potentially be easier to learn and apply than the conventional proving ring system.

7.4.2 Maintenance Requirements

The electronic mechanisms which make up the automated cone

penetrometer is a more complex system than the simple proving ring system. This change in components means that the maintenance levels involved in maintaining operational equipment increase. Coupled with this is additional maintenance training and study. However, since most of the maintenance personnel at the unit and higher levels are generally accustomed to high tech equipment maintenance, the relative increase in effort will potentially be small.

The Operator's Manual for the automated cone penetrometer as presented in Appendix A of this report makes an attempt to establish the bounds of maintenance performance at the operator level. If such a boundary is established, maintenance requirements will probably not be overwhelming and should in no way curtail further development or implementation of the automated system. Future generations of the automated cone system could implement calibration checks for both depth and load to facilitate operator detection of maintenance requirements.

7.4.3 Computer Requirements

As designed, the proposed automated system requires that a computer be made available to retrieve the measured soil resistance and depth of penetration data which is stored in the device's data logger. Even though the use of a computer allows the retrieved data to be more quickly and thoroughly analyzed, the requirement to transport a computer could be considered a

drawback to military units in a field environment. However, many of the Army's most advanced units currently depend on a computer for the daily management requirements of the unit (i.e. maintenance, personnel, and supply); therefore, it is suggested that computer requirements for analyzing the data measured with the automated cone penetrometer could easily be incorporated into this daily cycle with little effect on current practice. As presented in the text of this report, this research program used an IBM portable computer which is fully capable of being easily transported and operated in a field environment.

This need to utilize a computer is listed as a disadvantage only because of the fact that not "all" military units, at the present time, are equipped to function under daily computer requirements. As computers become more of a common item in military operational practice, this computer requirement should not be considered a great disadvantage for the conduct of extensive military trafficability studies.

7.4.4 Power Source Location

The current design requires four 9 volt transistor batteries be installed inside the apparatus for power supply requirements. In the initial generation system, the apparatus must be taken apart to check or replace these batteries. This is not a good design concept as opening the electronic control boxes at the

operator level each time the batteries need to be checked or replaced increases the risk of premature damage of the electronic components and wiring. Even under the extreme control exercised in the conduct of this research, the repetitious battery changes caused damage to the RS-232 communication wiring system inside the apparatus, resulting in rendering the apparatus temporarily non-operational.

7.5 RECOMMENDATIONS FOR EQUIPMENT MODIFICATIONS

The purpose of this section is to present specific equipment modifications for the automated cone penetrometer developed and tested in the context of this report. As noted throughout this report, the automated system tested in this research has proven beyond a reasonable doubt that it is much more efficient and effective in measuring soil resistance and depth of penetration than the proving ring system currently used. Note, however, that this is a first generation system and the following modifications will provide an even more efficient and effective apparatus for conducting military trafficability studies.

7.5.1 Separate Power Source Compartment

The power supply is currently located inside the two electronic compartments and is considered a great disadvantage to the present design. Therefore, it is suggested that the

batteries required to power the data logger, load cell, and potentiometer be located in an easily accessible compartment which is totally separated from the major wiring system of the apparatus. The design modification should provide a means by which these batteries can be internally recharged. Such a design will facilitate the need to change or recharge the batteries and reduce the possibility of damage to the delicate wiring system in the automated device.

7.5.2 Measure Cone Tip and Friction Sleeve Resistance

Current equipment developments in the field of in-situ soil testing provide a means of separating the cone tip and sleeve resistance values. By separating these values, a more accurate assessment of a soil's tip bearing capacity is measured. In addition, the use of the friction sleeve may allow better delineation of soil properties. It is recommended that a second generation automated military cone penetrometer be designed and fabricated to measure these values separately for future research.

One may question this recommendation from the basis that the current trafficability cone index values data base have been derived based on a design which combines both tip and sleeve resistance. This is a valid concern and should be a point of further study to quantify the effect of the separate readings. It is, however, noted that the military currently attempts to

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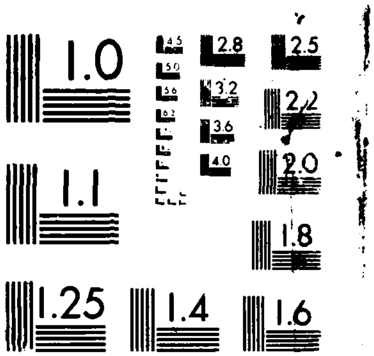

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establish a fine-grained soil's stickiness value in the conduct of trafficability studies via separate testing and analyses. Specifically, TM 5-330 states that the stickiness value of a soil is a measure of how much a particular soil will adhere to the running gear of a vehicle, thus possibly making travel and steering that much more difficult. If the cone penetrometer was designed to separate the cone tip and friction sleeve resistance, then a possible relationship between the sleeve resistance and stickiness value of a soil may be established. Such a design may enable the applicability of the current data base; a slight correction may be necessary.

7.5.3 Pore Pressure Measuring Device

In addition to a stickiness value, military trafficability studies attempt to establish a slipperiness value for a soil which is defined as a measure of a soil's water content (TM 5-330). The amount of water in a soil directly affects a vehicle's ability to steer and the ability of a soil mass to support sustained military traffic flow. In the design of cone penetrometers, current technological advancements provide a means by which the pore pressure generated by a penetrating cone in a soil can be measured by placing a pore pressure element in the vicinity of the cone tip. Such a modification may enable the military to establish a better understanding of soil's strength, permeability, and slipperiness particularly in soft saturated

soils. Pore pressur- measurements would also contribute to a thorough analysis of the remolded resistance, a measure of the soil's ability to support sustained military vehicle traffic.

7.5.4 Direct Cone Index Reading Capability

It is suggested that the controls and display window on the current device be reformatted such that the operator is able to read the cone index directly during the test; this would allow rapid assessment of subsurface characteristics and may reduce the requirement of data download onto a computer in certain instances. The purpose of this modification is to allow a quick assessment of a soil's trafficability if the need arises. After completing a particular cone penetration test, such a modification could possibly provide the operator with the ability to read from the display window the cone index value at each 4 or 6 inch increment of penetration depth. Therefore, the operator is able to quickly establish the trafficability of a particular soil mass. The 96 data points are still stored in the data logger for this penetration, thus, allowing a more thorough analysis at a later time.

7.6 RECOMMENDATIONS FOR FURTHER RESEARCH

In view of the success of the automated system presented in

the context of this report, it is highly recommended that further research be conducted and the next phase of this research commence. The proposed device provides a thorough and efficient means of meeting current demands on trafficability studies conducted on the highly technical modern battlefield. The following areas are suggested for further research.

7.6.1 X-Ray Photography of Cone Penetration

It is recommended that a series of laboratory-controlled penetration tests be conducted under x-ray control. The specific variables for study are expected to include the .5 and .2 square inch cones and homogeneous and non-homogeneous soil conditions. Conduct of these tests is expected to address the following key items:

(1) analyze the deformation process around the penetrating cone and relate this to the analytical equations established by Baladi and Rohani (1981).

(2) evaluate the boundary effects of the remolding kit's cylindrical test sample on soil resistance data measured with the two cones.

(3) evaluate the influence of alternating hard and soft soil layers on soil resistance and depth of

penetration data.

It is noted that the size of the cone would allow use of the x-ray facility already available at Georgia Tech. This facility has been utilized to penetrate 10 to 18 inch thick samples of sand and should prove adequate.

7.6.2 Conduct Cone Penetration in Calibration Chamber

It is recommended that a calibration chamber be constructed which will allow laboratory-controlled cone penetration testing in realistic soil conditions. This chamber would provide strict control to precisely model varying boundary conditions and degrees of saturation in a soil mass. The testing sequence should utilize the automated military cone penetrometer with the equipment modifications suggested in Section 7.5 and be conducted to:

(1) evaluate the application of the analytical model presented by Baladi and Rohani (1981).

(2) determine if the measured soil resistance values can be correlated to the engineering properties of a particular soil (cohesion, ϕ, and shear modulus).

(3) more accurately define the effects of concentrated

surface loads as applied by the operator of the cone penetrometer on the value of soil resistance.

(4) establish friction sleeve resistance and stickiness value for a particular soil to provide a possible correlation between these two values.

(5) evaluate the effect of pore pressure measurements on the ability of a soil to support sustained loading conditions.

(6) evaluate the effect of rate of penetration under varying boundary conditions and degrees of saturation.

(7) Conduct tests using sand, silts and clays prepared to a wide range of anticipated field conditions. The unique feature of this type calibration chamber is the size. Currently available chambers are approximately 3 feet in diameter, 5 feet deep, and capable of simulating confinement of 10's of feet of soil. This size is not needed for the automated military cone penetrometer because of the relatively small size of the prototype instrument and critical depth of interest. Thus, it could be relatively easilly adapted to the chamber at Georgia Tech used for the current study.

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APPENDIX A

AUTOMATED MILITARY CONE PENETROMETER

OPERATOR'S MANUAL

TABLE OF CONTENTS

OPERATOR'S MANUAL

INTRODUCTION

This manual provides a "STAND ALONE" step-by-step procedural outline on the set-up, use and data retrieving processes involved in working with the automated military cone penetrometer. Several hard copy examples are presented at the end of this manual to aid in the various steps of operation. Prior to the conduct of any operation using the automated cone penetrometer, the operator should insure that he or she fully understands where each component of this device is located and its particular function. It is imperative that all personnel study and understand the following section which explains the location and function of the various components prior to beginning any operation with this device. Without a thorough understanding of the components, the operator runs the risk of possibly losing valuable data.

OVERVIEW OF THE AUTOMATED CONE PENETROMETER OPERATION

The cone penetrometer is the primary instrument utilized by the Armed Forces in establishing the trafficability of a selected segment of terrain. In this design the conventional proving ring

system was replaced with a load cell to determine soil resistance, a potentiometer to establish the depth of penetration and a data logger for storing this data from a series of tests to form an automated data acquisition system. Figures 1 & 2, at the end of the next section, depict drawings of (1) the complete automated cone penetrometer package in the storage position and (2) the controls at the top of both the Control and Loading boxes. The control box is configured with an outlet which can be connected to a computer by use of a RS232 cable to retrieve the data from the data logger. This data can then be analyzed to establish a continuous profile of the terrain over a two foot depth.

The automation of this system provides many advantages of which the most important are:

* that the control of the automated data acquisition system is straightforward and therefore easily applied with no change in the actual technique utilized to push the cone penetrometer.

* the elimination of detailed recording of cone resistance and depth by the operators during the conduct of the test and thus reducing possible errors.

* the elimination of an assistant as the automated system is truly a one man operation.

* a more efficient means of gathering data by speeding up the overall data gathering process.

* that the device is much more sensitive than the proving

ring system and is therefore able to better define the thickness of a desiccated crust and non-homogeneity of a soil mass.

* the ability to conduct numerous penetrations before the data must be down-loaded from the data logger by use of a computer. The number of penetration tests which can be conducted is actually a function of the software utilized in down-loading the data. This will be further discussed in the section on "Retrieving Data".

* that a continuous profile of a penetration is provided in the down-loaded data which can be quickly analyzed to evaluate the trafficability of the given terrain. The values of cone index are the same as those previously utilized with the standard proving ring cone penetrometer.

LIST OF COMPONENTS AND FUNCTION

The automated cone penetrometer device consists of five major components:(1) Control Box, (2) Loading Box, (3) Base Plate, (4) Shaft, and (5) Cone. The Control and Loading boxes are actually attached to a common plate for more efficient use; however, each is considered as a separate entity because of their particular functions. Figures 1 and 2 at the end of this manual depict the location of these various components and should be referenced as you proceed through this section. The following paragraphs will define the particular function of these

components with subsequent sections in the manual providing detailed procedures for the use of these components to accomplish specific tasks.

Control Box

This box contains the data acquisition which is the brains of the automated military cone penetration device. The electrical components in this box contain the data logger which interprets and stores the data from a penetration test; therefore, special care should be taken to insure that this box is not damaged in any fashion. This box contains an outlet which enables the attachment of a RS232 cable to link the data logger to a computer for down-loading data from penetration tests. The operator utilizes this box to control the functions desired by manipulating or viewing the following components on the top face (Reference Figure 2):

Battery Switch - The purpose of this switch is to establish the source which will power the load cell, potentiometer and data logger in the apparatus. This switch is set up to provide the operator with the capability of utilizing the cone penetrometer on the **INTERNAL** power source of two 9-volt batteries in both the control and loading boxes or on an **EXTERNAL** 12-volt battery which can be connected by cable to the device. The switch has three positions: (1) up to **EXTERNAL** source, (2) down to **INTERNAL**

source, and (3) middle for OFF. The **EXTERNAL** mode is more likely to be used in maintenance repair operation or calibration testing; thus, this manual will consider only the **INTERNAL** power source which is considered the most feasible for combat units in a field environment.

RUN/STOP Switch - This switch is utilized to control the operation of the data logger. The switch must be placed in the **RUN** position in order for any mode/function to be initiated. Upon completion of a function the switch must be placed in the **STOP** position to indicate the completion of this particular function. Failure to insure that these switches are in the proper position will probably result in improper data acquisition.

Mode Selector Switch - This switch is utilized to indicate the particular function that the user desires. The switch must be in the proper mode of operation prior to placing the **RUN/STOP** switch in the **RUN** position. This switch provides the operator the capability of choosing from five separate functions:

1. **MARK** - To **MARK** one particular set of cone penetration test data. An example could be that during the conduct of a penetration test the operator hits a solid surface (e.g. large rock) and wants to separately identify this test when the data from all testing is retrieved. Specific situations where a

particular test is to be **MARKed** should be designated in the Standard Operating Procedures (SOP) of a unit.

2. **DUMP** - To communicate with the data logger via computers. Utilized to retrieve test data and to modify the existing program within the data logger.(Note: At no time should the program be modified except by qualified personnel. In addition, a possible shortfall or benefit, depending on how one considers it, of the Model IV, Onset Tattletale device is that the program is not burned into memory and can be altered.)

3. **CLEAR** - Utilized to erase all of the old test data from the memory of the data logger prior to running a new test series. (Note: Insure that all data is completely saved prior to initiating the **CLEAR** mode of operation or all of the data presently logged in the apparatus will be lost.)

4. 1, .5 and .2 Inch - Utilized to place the data logger in the data gathering function. The operator should choose the mode which corresponds to the particular cone base area being used for a given data gathering session.

6. **CAL** - Utilized to check the calibration of the load cell and potentiometer within the apparatus.

A detailed discussion of each of the above functions is outlined

in subsequent sections of this manual.

AREA Designation Panel - The two finger buttons on this panel are utilized to designate test areas. This switch allows test data to be separated and analyzed for a specific area. The program in the data logger is set up to automatically increment each penetration test based on the data from the potentiometer which electronically informs the logger that a 24 inch penetration is complete to establish the sequential test number for this penetration. The AREA designation provides an additional control measure to establish different test sites/AREAs which may be tested within a given testing sequence prior to the data being down-loaded and then CLEARed from the memory of the data logger.

R/S Button - Utilized to initiate the execution of certain functions chosen from the Mode selector switch. This button will be further discussed in the outline of functional procedures.

Green Light - Utilized to provide visual proof to the operator that a particular function is in the process of being executed or has been completed. Further discussion to follow.

Display Window (Liquid Crystal Display) - Utilized to provide a visual digital display of particular functions chosen from the Mode selection. Further discussion to follow.

Loading Box

This box contains the load cell which provides the means for measuring the resistance of the soil being tested and the potentiometer which measures the penetration distance. A standard military cone penetrometer handle is located on the top face of this box to provide the platform for the operator to place his/her hands in applying the force required to cause the cone to penetrate the soil (Reference Figure 2). A clip attached to a wire is located on the bottom of this box. This clip is attached to the base plate, which the operator stands on during the conduct of a test, to allow the distance of penetration to be logged by the potentiometer.

Base Plate

This plate provides the support for the clip to the potentiometer, the operator with a foot rest during penetration testing, and a hole in the center portion of the plate which aids the operator in minimizing eccentric loading conditions and to allow passage of the penetrometer shaft through the plate. The bottom of the loading box has four magnets which are utilized to secure the base plate in the storage position, flush to the bottom of the box as depicted in Figure 1.

Shaft and Cone

The Military's standard 3/8 or 5/8 inch shaft, 30 inches in length, is attached to the load cell at the bottom of the loading box. A 30-degree cone of 1, .5 or .2 square inches in base area is attached to the end of the shaft. A washer just small enough to keep from freely passing through the hole in the base plate is placed on the shaft oetween the cone and the bottom of the base plate. This washer will aid in eliminating the possibility of overextending the wire of the potentiometer and damaging the device.

GETTING STARTED

1. Inventory the equipment to insure that each of the five components listed previously are present.

2. Insure the battery switch is in the middle (**OFF**) position and the **RUN/STOP** switch is in the **STOP** position.

3. Insure that you have four fresh 9-volt batteries that will provide at least 8.5 volts of power. Check the batteries with a voltmeter to insure proper voltage. Insert two internal 9-volt batteries into each box. The four screws at the top of each box must be loosened in order that the top face of each can be removed and the batteries inserted into their respective storage compartments. Secure the top face of each box by re-tightening the screws. CAUTION: Insure that the battery poles are properly positioned prior to insertion to minimize possibility of grounding the circuitry. Special care must be taken to insure that this step is completed in a very delicate manner. Insure that none of the internal electrical circuitry is handled in any fashion. In addition, insure that the wires are not caught between the top face and the frame of the box when securing the top face.

4. Check to insure that the device is operating properly.

Place the **AREA** switch in any area 2 through 9, the battery switch in the **INTERNAL** position, and the **RUN/STOP** switch in the **RUN** position. Once the device is in the **RUN** configuration the operator should see **ØØ** in the display window. If display is present then proceed to step 7, if not present, then continue with step 5.

5. Repeat steps 2 through 4 above.

6. If display is still not present, then return the device to qualified maintenance personnel.

7. Insure the battery switch is in the middle (OFF) position and the **RUN/STOP** switch is in the **STOP** position. The device has now been tested and is ready for use in completing one of the tasks presented in the following sections.

8. Once all tasks have been completed with the automated military cone penetrometer, the two batteries in the loading box should be removed. The batteries in this box will drain because of internal circuitry and therefore need to be replaced approximately every six to eight hours unless removed.

9. Insure that the data logbook sheet is properly prepared prior to the conduct of any test to minimize time in the field.

A sample logbook sheet can be found at the end of this manual in Figure 3.

CALIBRATION

Only qualified maintenance personnel should perform detailed calibration of circuitry within the device. However, all operators should perform the following steps to insure that the initial calibration of the device is properly established.

1. Insure that the battery switch is **OFF** and the **RUN/STOP** is in the **STOP** position.

2. Turn the mode selector switch to the **CAL** position.

3. Place the battery switch in the **INTERNAL** position.

4. Place the **AREA** designation in the **Ø** position.

5. Place the **RUN/STOP** switch in the **RUN** position. Once in the **RUN** position, hold the Control and Loading boxes in your hands insuring that the load cell stem at the bottom of the loading box is not touched. The display window should read approximately **1ØØ** when the device is placed under self weight.

6. Place the **AREA** designation in the **1** position to check the potentiometer. The display window should read approximately 749 when the base plate is secure to the bottom of the loading

box.

7. If either reading is extremely erratic (greater than $\pm$ 2%), then check the batteries, replace the batteries if need be, and repeat the above steps. If the readings are still erratic, then return the apparatus to qualified maintenance personnel for evaluation.

8. Place the **RUN/STOP** switch in the **STOP** position and turn the battery switch **OFF**.

CONDUCTING A TEST

1. Insure data has been **CLEARed** from memory, if desired, prior to performing any tests.

2. Attach the potentiometer clip at the bottom of the Loading box to the base plate and secure the base plate to the bottom of the Loading box by use of the magnets. Insure that the extension for the attachment of the shaft is in the center of the hole in the base plate.

3. Place the washer on the shaft and attach the appropriate cone tip to the end of the shaft. Attach the shaft to the bottom of the loading box when ready for testing. The shaft is threaded and will screw into the load cell extension.

4. Insure the battery switch is **OFF** and the **RUN/STOP** switch is in the **STOP** position.

5. Place the mode selector switch in the .2, .5, or 1 inch position whichever corresponds to the base area of the cone which is being used for the particular penetration.

6. Select the **AREA** designation which corresponds to the site being tested and as specified in accordance with the unit's

SOP. Annotate the field data log book accordingly.

7. Position the base plate at its full distance from the loading box and flush on the ground where the penetration is to be made. Place feet on the foot pads to brace the base plate and hold the device in the upright position by the cone handle, insuring that the cone tip is between the bottom of the base plate and the ground surface. (NOTE: Insure that the cone tip does not retract through the hole in the base plate. A washer, as previously discussed, should be placed between the cone and the base plate. This will alleviate any possibility of pulling the distance wire too far and damaging the potentiometer.)

8. Place the battery switch in the **INTERNAL** position.

9. Place the **RUN/STOP** switch in the **RUN** position.
NOTE: Insure that the cone tip is not in contact with the soil prior to beginning this step. Otherwise, the test data may be erroneous.

10. Slowly position the cone tip to the soil surface where the penetration is to be made. Insure that the shaft remains in a vertical position throughout the conduct of the test to eliminate any possible errors which could arise do to eccentric loading. The operator should position his/her hands one over the other, at right angles, on the cone handle and slowly apply force

to the device. The green light should glow once the base of the cone is flush with the soil surface to designate that the device is gathering data as penetration is made. The desired rate of penetration is approximately 1.2 inches per second. The green light will turn off once the penetration has been made to a depth of 24 inches. Test data is gathered every .25 inches which should provide approximately 96 data points per test penetration. This rate is software dependent and an adjustment of the software can yield more data points if needed.

11. Once the green light turns **OFF**, place the **RUN/STOP** switch in the **STOP** position and secure the base plate to the bottom of the loading box by use of the magnets. Slowly retract the cone tip from the soil by pulling on the cone handle.

12. Repeat steps 6 through 11 as required. It is noted that the automated device will sequentially number the penetration tests in the order they are conducted. After completion of each penetration, insure that the **AREA** and penetration number are properly recorded in the field data log. The **RUN/STOP** switch can be placed in the **STOP** position at any point during the conduct of a penetration to stop a particular test. The data collected from a test stopped short will be saved in the data logger under the sequential test number for that

particular penetration. Once all tests have been completed for a given AREA the battery switch should be placed in the OFF position.

MARKING A TEST

This function provides the operator a means of marking a test because of special situations which may arise during the conduct of that particular penetration. The marking of a penetration test must be completed prior to the conduct of another penetration. An example of the need to mark a particular test may be the fact that during the conduct of a penetration the operator was not able to fully penetrate the total 24 inches because of an obstruction. When the **MARKed** data is retrieved as explained in the next section, the marked penetrations will have a 1 designation while all unmarked penetrations will be designated as Ø's in the **MARK** section of the retrieved data.(See Figure 6)

1. Place the **RUN/STOP** switch in the **STOP** position.

2. Place the mode selector switch in the **MARK** mode.

3. Insure that the battery switch is in the **INTERNAL** position.

4. Place the **RUN/STOP** in the **RUN** position.

5. Push the **R/S** button. The **green light** should blink on

and then off, once. This designates that the preceding penetration has been **MARKed** to designate whatever the operator desires. Insure that proper annotation of the reason for marking has been properly logged into the data book.

6. Place the **RUN/STOP** switch in the **STOP** position and continue with next desired function.

RETRIEVING DATA

This functional step outline will enable the automated military cone or computer operator the capability to retrieve the data that has been stored in the automated penetrometer's data logger. The following steps have been developed to utilize the following hardware and software:

Hardware: IBM PC, IBM PC Convertible, or IBM Compatible with MODEM capability.

RS232 Cable with appropriate jack to link the ONSET Tattletale Model IV Data Logger with the computer's modem. A special cable, the TC-4 cable, must be utilized to accomplish this task due to the internal circuitry of the data logger. Figure 4 provides a picture of the TC-4 with the automated data acquisition device.

Software: Communication's Software with required parameters set to communicate with the ONSET data logger. The MIRROR Communication's software will be utilized for this procedure with the filename of Tattle for the parameter settings.

Use of other communication's software such as Crosstalk and PC-Talk is acceptable. The steps which follow assume that the communication's software has already been configured to communicate with the Tattletale data logger in the device. The parameters for setup of the communications software are as follows:

Baud Rate - 9600

Parity - no

Data Bits - 8

Stop Bits - 0

1. Insure that the battery switch is **OFF** and the **RUN/STOP** switch is in the **STOP** position.

2. Attach the male end of the ONSET TC-4 cable to the Control box and the female end to the computer's MODEM port.

3. Insure the computer has been properly booted into DOS and place the Mirror communication's software disk in the specified drive as prompted and type: **MIRROR** and press the carriage return/enter<CR>. The screen should look like Figure 5.

4. Enter the number which corresponds to Tattle and press <CR>. A blank screen with a blinking cursor should appear.

5. Place the battery switch in the **INTERNAL** position and

the **RUN/STOP** switch in the **RUN** position. Important, insure these switches are properly placed in this prescribed order. Insure the **Caps Lock** switch is on. The screen should depict the following line:

'TURN CAPTURE ON IF YOU WANT TO SAVE THE DATA <CR>'

Press <CR>. At this time the data of the first penetration test conducted should scroll across the screen.

6. Once the data has finished scrolling the following text should be depicted on your screen:

'TURN CAPTURE OFF'

'CONTINUE <1> OR STOP <2>'

At this command enter 2 and press <CR>. The following prompt should appear: OK

>

7. Type: N=X <CR>, where X is the actual number of tests that need to be retrieved. After pressing the <CR> the OK prompt should appear again. It is noted that all test will appear in sequential order; therefore, X should be equal to the total number of tests that were conducted in order to retrieve all data at once. The value of X is totally dependent on the number of test penetrations that you have completed. Presently, the design does not allow a single test to be randomly retrieved from the data logger; therefore, all pertinent data must be retrieved simultaneously. Also, the software that is being used for

analyses may limit the number of test penetrations that can effectively be used. For example, when using LOTUS 1,2,3 to analyze the retrieved data, the maximum number of tests that can be imported into a LOTUS file at any one time is 5. Editing programs, which enable the operator to separate the master file of all penetration tests into individual files, would provide a means of retrieving many more tests. Individual tests cannot be retrieved unless the first test is the only one retrieved.

8. Type: **GOTO 9000** and press <CR>. The **Turn Capture On** reminder should appear.

9. Press **<ESC>** and at the bottom of the screen the prompt of '**COMMAND:**' should appear. Enter in capital letters '**CA B:FILENAME.PRN**' and press <CR>. The filename is the choice of the operator with a limitation of eight characters which will aid in describing the tested location or conditions. The extension of **.PRN** must be entered as such so that the data saved can be imported into the LOTUS spreadsheet for further analyses. The data from the X number of tests should start to be saved into the designated file in Drive B at the time the carriage return is pressed.

10. When the prompt to **CONTINUE OR STOP** appears enter 2 and press <CR>.

11. Press <ESC> and at the **COMMAND:** prompt type '**CA OFF**'. Press <CR>. This insures that the data sent to the file in Drive B is totally accepted. Data in the file is stored as shown in Figure 6.

12. At the OK prompt type '**RUN**' and press <CR>. The **green light** on the control box should blink on and then off to show that the variables for the program have been reestablished and the device is ready for use in additional penetration testing.

13. Place the **RUN/STOP** switch in the **STOP** position and turn the battery switch **OFF**.

14. Press <ESC> and type '**QU**' at the **COMMAND:** prompt. Press <CR>. The DOS prompt for the given drive should appear.

15. Detach the ONSET TC-4 cable from the control box.

16. Data from the tests have now been saved under the file, Filename.PRN and are ready to be manipulated by use of an electronic spreadsheet. At this point the device is ready to be taken to the field to retrieve additional data. Unless the memory is **CLEAR**ed, the previous retrieved test data will remain logged and subsequent test data will be numbered in sequential order starting from where the previous data had ended. It is good practice at this point to check the data file created to

insure that all data has been properly retrieved and the memory of the data logger **CLEAR**ed when satisfied.

CLEARING THE MEMORY

This procedure allows the operator to clear the memory of any past data that is no longer desired for operational reasons. It is good practice to insure that prior to clearing any data a check is made of the data currently in memory and recorded if necessary. Once the data has been cleared then it can no longer be retrieved.

1. Insure the battery switch is **OFF** and that the **RUN/STOP** switch is in the **STOP** position.

2. Turn the mode selector switch to the **CLEAR** mode.

3. Place the area designation in **AREA Ø**.

4. Place the battery switch in the **INTERNAL** mode and the **RUN/STOP** switch in the **RUN** position.

5. **Press the R/S** button. The **green light** should flash twice. If the green light does not come on then repeat steps 1 through 5. If no green light appears return the apparatus to qualified maintenance personnel.

6. The completion of the second green light flash

designates that the memory has been cleared.

7. Place the **RUN/STOP** switch in the **STOP** position and the battery switch in **OFF**.

ANALYZING THE DATA

This procedural outline will utilize the LOTUS 1,2,3 electronic spreadsheet and graphics software to analyze the data retrieved from the ONSET Tattletale data logger. Other spreadsheets with graphics and importing capabilities can be utilized.

1. Establish a blank spreadsheet file in the LOTUS program as shown in Figure 7.

2. Import the file of the data that is desired to be analyzed. To accomplish this task, first place the cursor just outside of the right edge of the established spreadsheet so that the data from all of the tests can be imported and remain throughout the process of manipulation. In the command menu for LOTUS enter the file import command and retrieve the data file you created in the 'Retrieving Data' section.

3. Move the desired test data numbers for the 'DEPTH, LOAD, TIME' to the appropriate location in the blank spreadsheet. The load data is in pounds and must therefore be divided by the base area of the cone used. The depth is in inches and should therefore be only multiplied by a negative one to develop a spreadsheet as shown in Figure 8.

4. Utilizing the 'GRAPH' menu of commands develop a plot with the DEPTH as the 'y' axis and the CONE INDEX as the 'x' axis. Figure 9 depicts a plot utilizing this technique.

5. Enter the command menu and save this plot and spreadsheet under an appropriate filename.

6. Once this penetration test data sequence has been saved the next set of test data from the imported section to the right of the spreadsheet can be moved into the appropriate columns and manipulated as stated in steps 3 through 5 above. These procedures are continued until all of the imported data has been analyzed.

7. Hard copies of the spreadsheets and the plots (as shown in Figures 8 and 9) can be obtained by entering the appropriate menu of the LOTUS program (1,2,3 for the spreadsheet and PRINTGRAPH for the plots) and printing them.

FIGURE 1

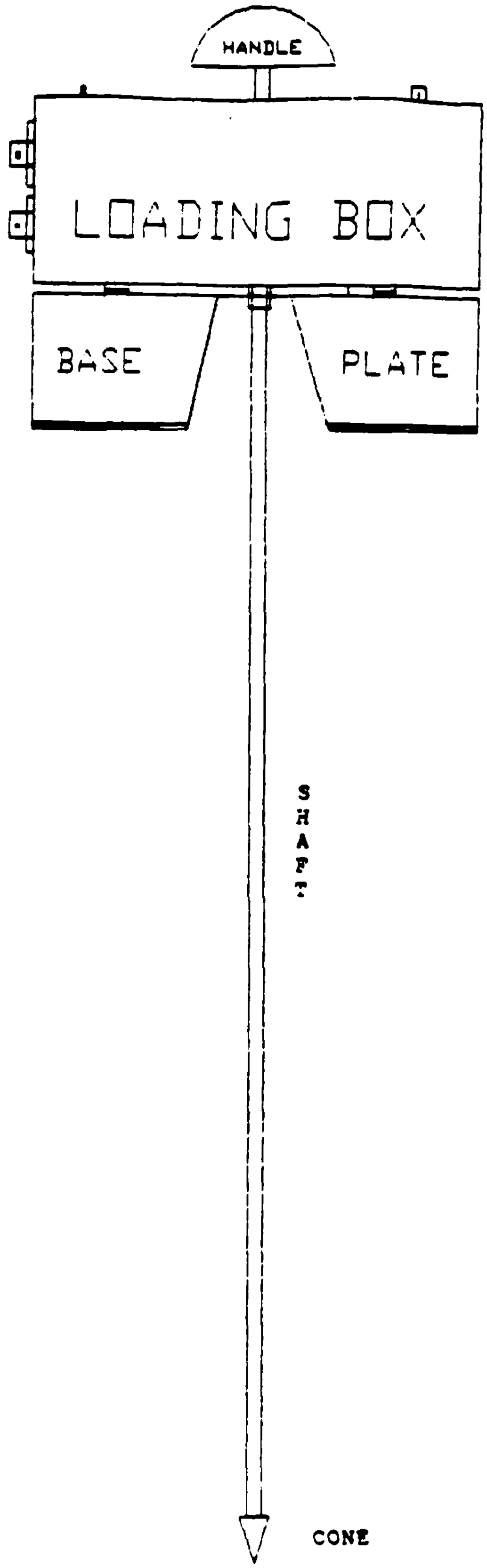


FIGURE 2

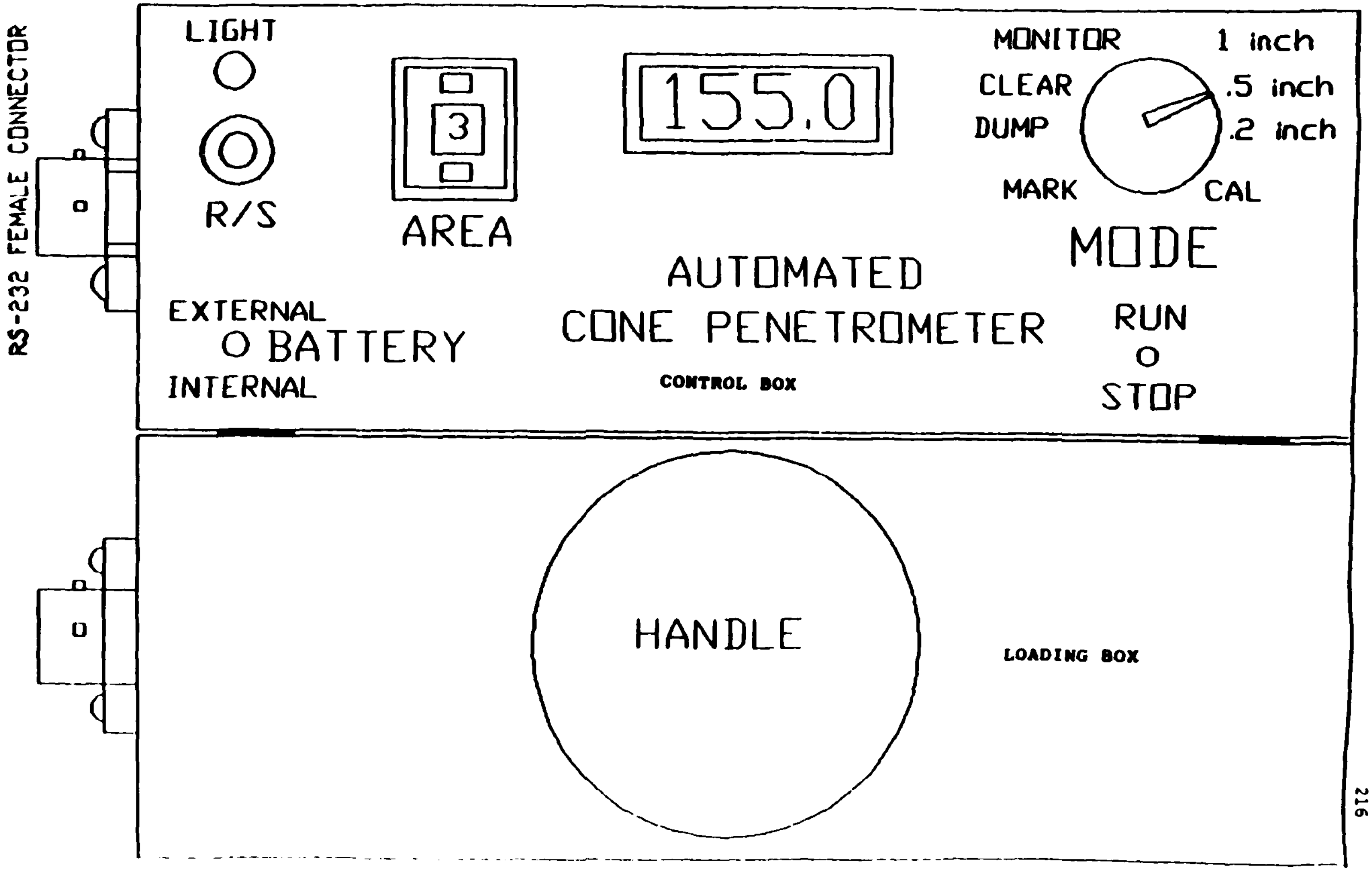

RS-232 FEMALE CONNECTOR
LIGHT
R/S
AREA
3
155.0
MONITOR
CLEAR
DUMP
MARK
1 inch
.5 inch
.2 inch
CAL
MODE
AUTOMATED
CONE PENETROMETER
EXTERNAL
BATTERY
INTERNAL
RUN
STOP
CONTROL BOX
HANDLE
LOADING BOX

FIGURE 7. DATA LOGBOOK SHEET

AUTOMATED CONE PENETROMETER DATA LOG SHEET

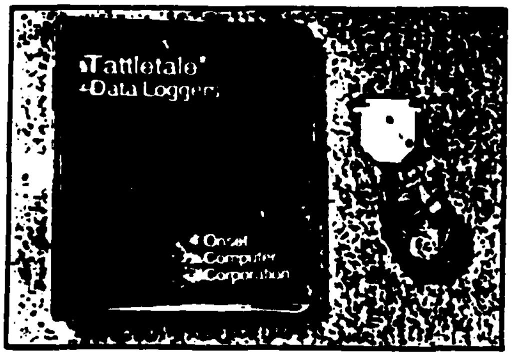
DATE ______________ UNIT ______________________________

OPERATOR ________________ LOCATION ________________________

WEATHER CONDITION ____

TEST #	AREA	CONE SIZE	MARK EB NO	REMARKS

FIGURE 4



TC-4 Interface cable, Manual

FIGURE 5

```
                ZDDDDDDDDDDDD MIRROR Status Screen DDDDDDDDDDD?      Off-line

 NAme   MIRROR Default Settings                        LOaded    STD.XTK
 NUmber                                                CApture   Off

ZDDDDDDDD Communications parameters DDDDDDDD?   ZDDDDDD Filter settings DDDDDDD?
 SPeed  4800  PArity None    DUplex  Full         DEbug     Off   LFauto    Off
 DAta   8     STop    1      EMulate None         TAbex     Off   BLankex   Off
 POrt   1                    MOde    Call         INfilter  On    OUtfiltr  On

ZDDDDDDDDDDDDDDD Key settings DDDDDDDDDDDDDDD?  ZDDDD SEnd control settings DDD?
 ATten  Esc                  COmmand ETX (^C)     CWait    None
 SWitch Home                 BReak   End          LWait    None

ZDDDDDDDDDDDDDDDDDDDDDDDDDD Available command files DDDDDDDDDDDDDDDDDDDDDDDDDDDD?

  1) CA          2) HONEYWEL    3) IBMAN       4) IBMCL       5) NEWUSER
  6) SETUP       7) STD         8) TATTLE      9) VAX        10) VAXMSD

 Enter number for file to use ( 1 - 10 ): 8
```

FIGURE 6 , DATA RETRIEVED FROM THE TATTLETALE

TURN CAPTURE ON IF YOU WANT TO SAVE THE DATA <CR>

AREA= 4:	TEST #= 1:		AREA= 5:	TEST #= 2:	
CONE= 7:		MARK= 0:	CONE= 7:		MARK= 1:
DEPTH	LOAD	TIME	DEPTH	LOAD	TIME
0.00	0.00	3.54	0.00	0.00	3.622
0.25	0.00	7.23	0.25	0.00	7.14
0.50	0.00	11.09	0.50	0.00	11.04
0.75	0.00	14.31	0.75	0.00	14.24
1.00	0.00	18.44	1.00	0.00	18.65
1.25	0.42	22.04	1.25	0.00	22.14
1.50	0.85	25.80	1.50	0.42	26.06
1.75	1.27	29.23	1.75	1.27	29.56
2.00	1.70	33.29	2.00	1.70	33.60
2.25	2.12	37.14	2.25	2.12	37.34
2.50	2.55	40.86	2.50	2.55	41.19
2.75	2.55	44.22	2.75	2.55	44.66
3.00	2.55	48.26	3.00	2.97	48.59
3.25	2.55	51.92	3.25	2.55	52.33
3.51	2.55	55.47	3.51	2.55	55.88
3.76	2.55	58.91	3.76	2.55	59.41
4.01	2.55	62.93	4.01	2.12	63.60
4.26	2.55	66.61	4.26	1.70	67.15
4.51	2.12	70.35	4.51	1.70	71.08
4.76	2.12	73.94	4.76	1.70	74.65
5.01	2.12	78.15	5.01	1.70	78.90
5.26	2.55	81.74	5.26	1.70	82.47
5.51	2.55	85.48	5.51	2.12	86.36
5.76	2.55	88.99	5.76	2.55	89.85
6.01	2.12	92.92	6.01	2.97	93.82
6.26	2.12	96.43	6.26	3.40	97.26
6.51	2.12	100.21	6.51	3.82	101.21
6.76	2.12	103.70	6.76	4.25	104.82
7.02	2.12	107.65	7.02	4.68	108.79
7.27	2.55	111.37	7.27	4.68	112.40
7.52	2.55	115.30	7.52	4.25	116.56
7.77	2.97	118.81	7.77	4.25	120.04
8.02	3.82	122.84	8.02	4.25	124.20

FIGURE 7

BLANK FORMATTED SPREADSHEET TO MANIPULATE
DATA FROM CONE PENETRATION TESTING

AREA= 9: TEST #= 5:
CONE= 6: MARK= 0:

DEPTH (INCHES)	LOAD (LBS)	TIME (SEC)	CI (PSI)	DEPTH (INCHES)
A12	B12		+B12/.5	+A12*-1

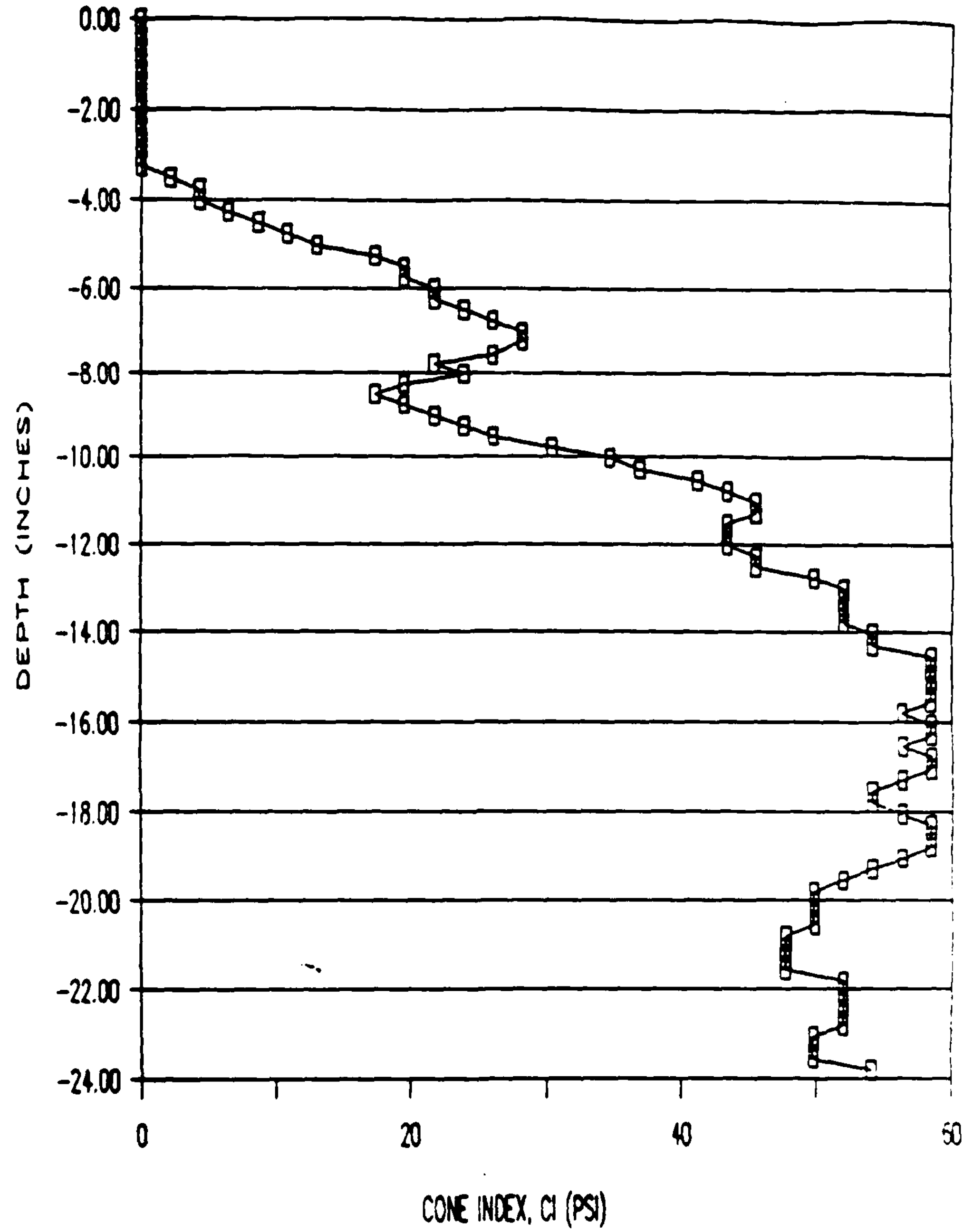
FIGURE 8. LOTUS SPREADSHEET

AREA= 4: TEST #= 3 DENSITY = 36.43
CONE= 3: MARK= 1:

DEPTH (INCHES)	LOAD (LBS)	TIME (SEC)	CI (PSI)	DEPTH (INCHES)
0	0	3.78	0.00	0
0.25	0	7.34	0.00	-0.25
0.5	0	11.23	0.00	-0.5
0.75	0	14.67	0.00	-0.75
1	0.42	18.97	0.84	-1
1.25	0.85	22.62	1.70	-1.25
1.5	1.27	26.53	2.54	-1.5
1.75	2.12	30.22	4.24	-1.75
2	2.55	34.34	5.10	-2
2.25	2.97	38.23	5.94	-2.25
2.5	2.97	42.12	5.94	-2.5
2.75	3.4	45.71	6.80	-2.75
3	3.82	49.85	7.64	-3
3.25	4.25	53.44	8.50	-3.25
3.51	4.68	57.19	9.36	-3.51
3.76	5.1	61.13	10.20	-3.76
4.01	5.53	65.23	11.06	-4.01
4.26	5.95	68.97	11.90	-4.26
4.51	6.38	72.92	12.76	-4.51
4.76	7.23	76.65	14.46	-4.76
5.01	7.65	80.89	15.30	-5.01
5.26	8.51	84.59	17.02	-5.26
5.51	9.36	88.48	18.72	-5.51
5.76	9.78	92.07	19.56	-5.76
6.01	10.21	96.15	20.42	-6.01
6.26	11.06	99.75	22.12	-6.26
6.51	11.48	103.67	22.96	-6.51
6.76	12.34	107.23	24.68	-6.76
7.02	12.76	111.43	25.52	-7.02
7.27	13.19	114.9	26.38	-7.27

FIGURE 9

CONE INDEX VS. DEPTH, DENSITY=88.16



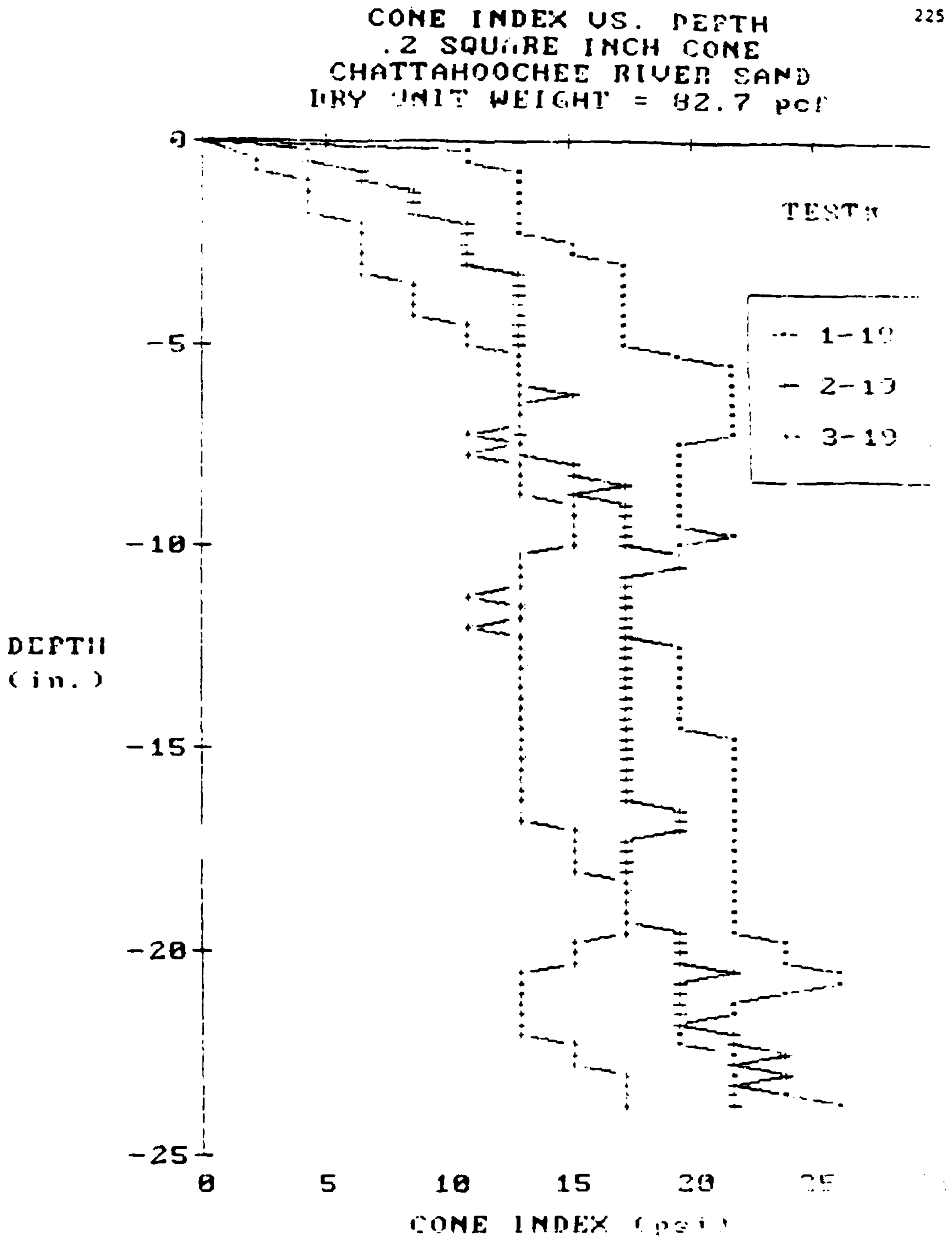
APPENDIX B

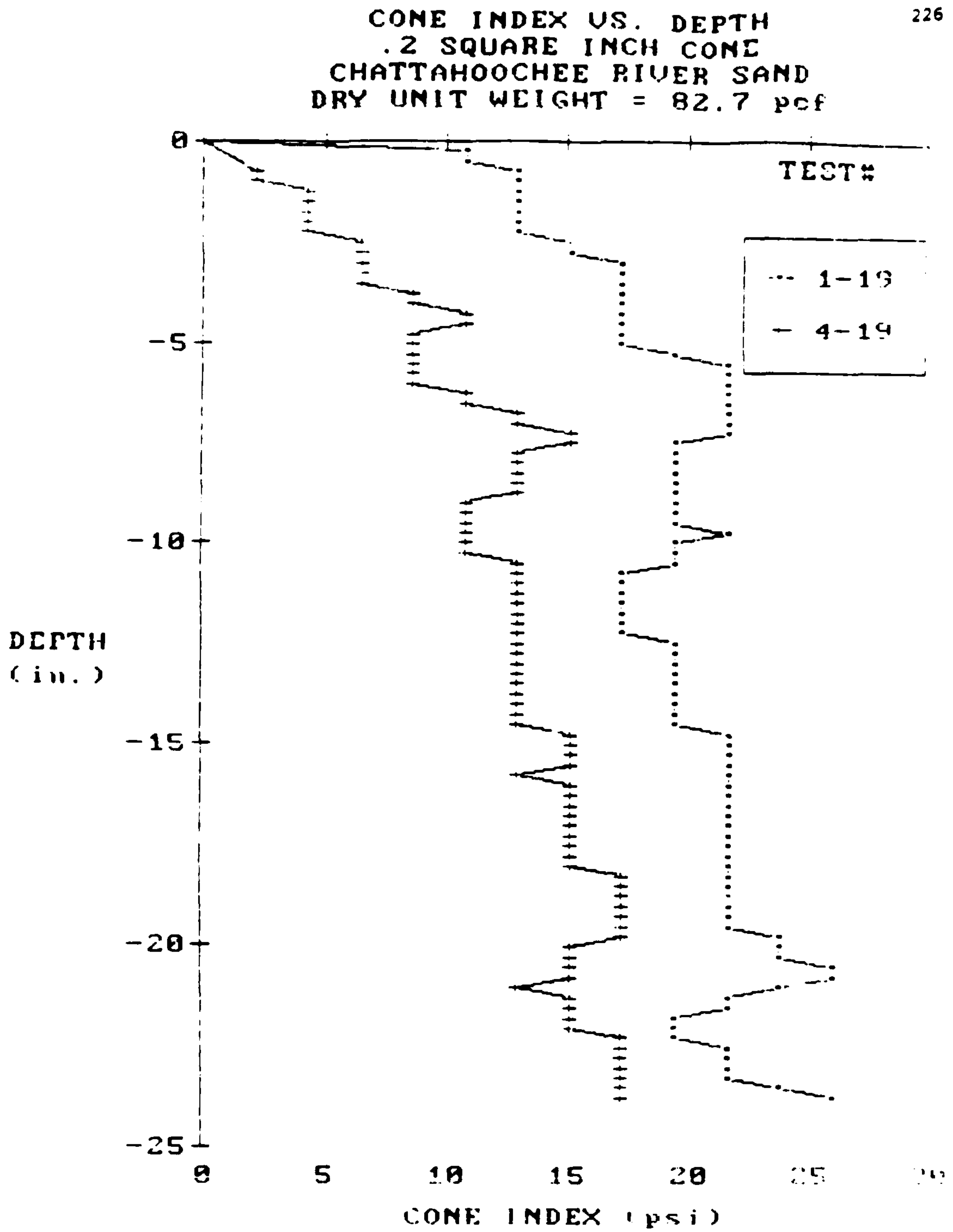
CHATTAHOOCHEE RIVER SAND

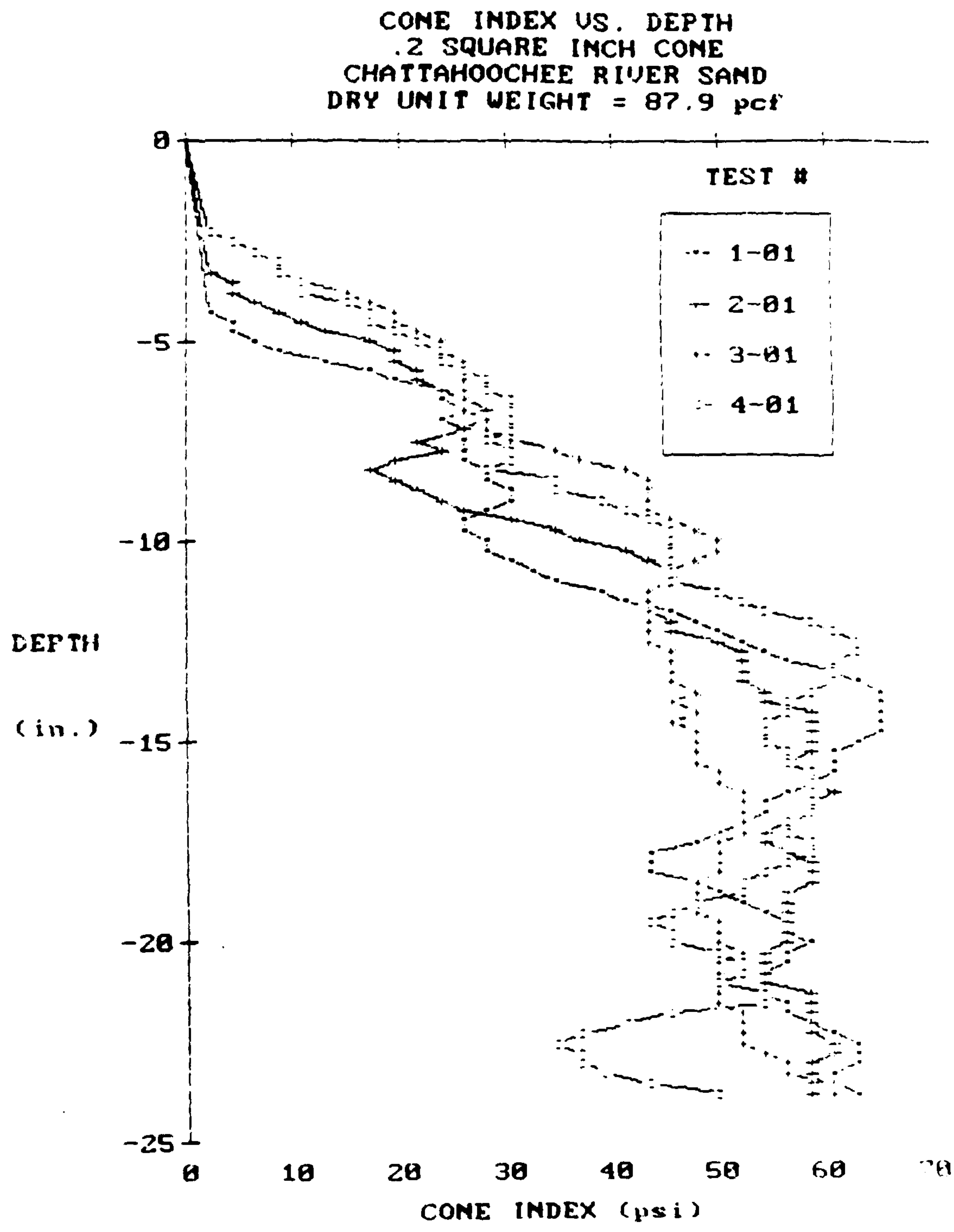
AUTOMATED MILITARY CONE PENETROMETER

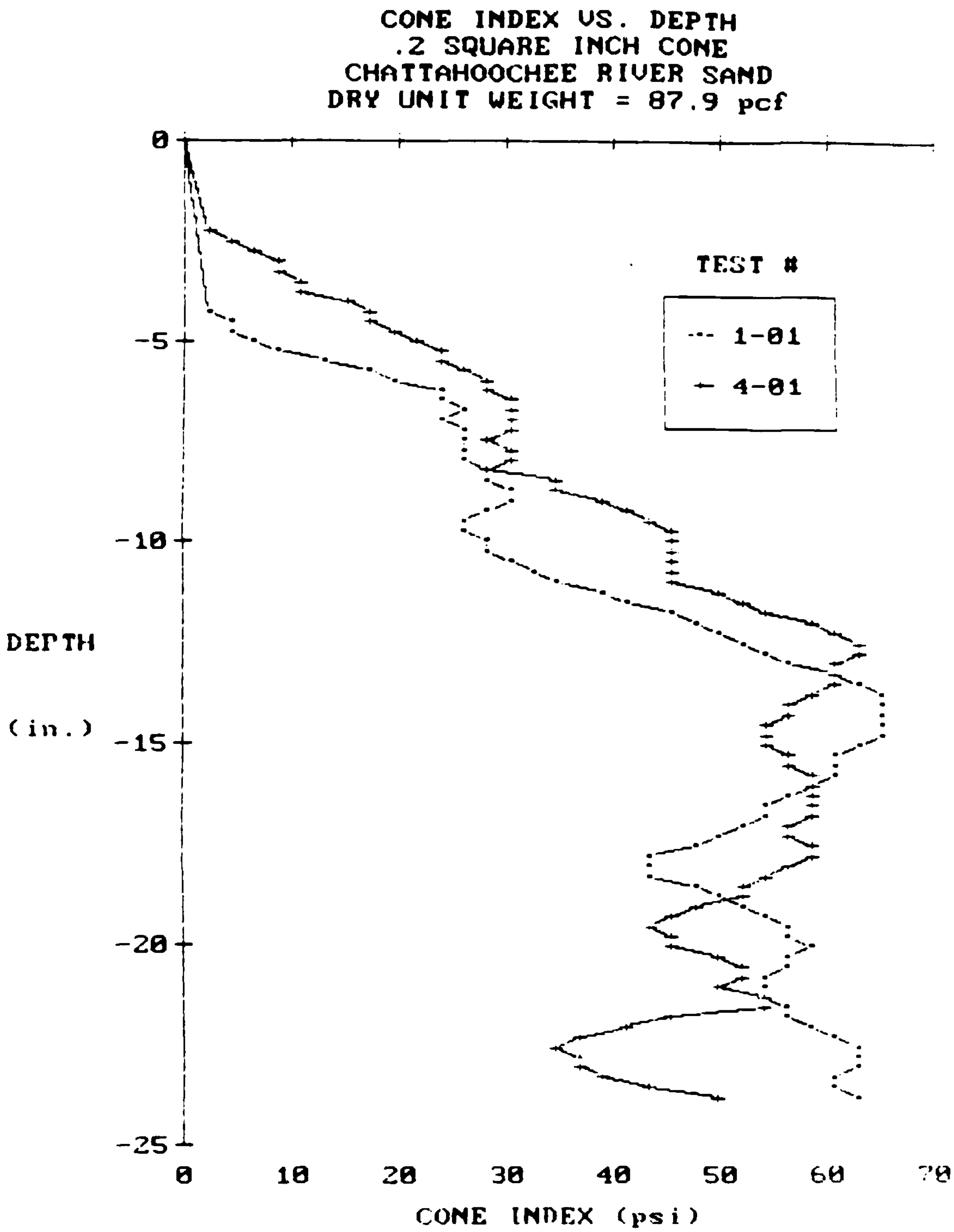
GEORGIA INSTITUTE OF TECHNOLOGY

ATLANTA, GEORGIA

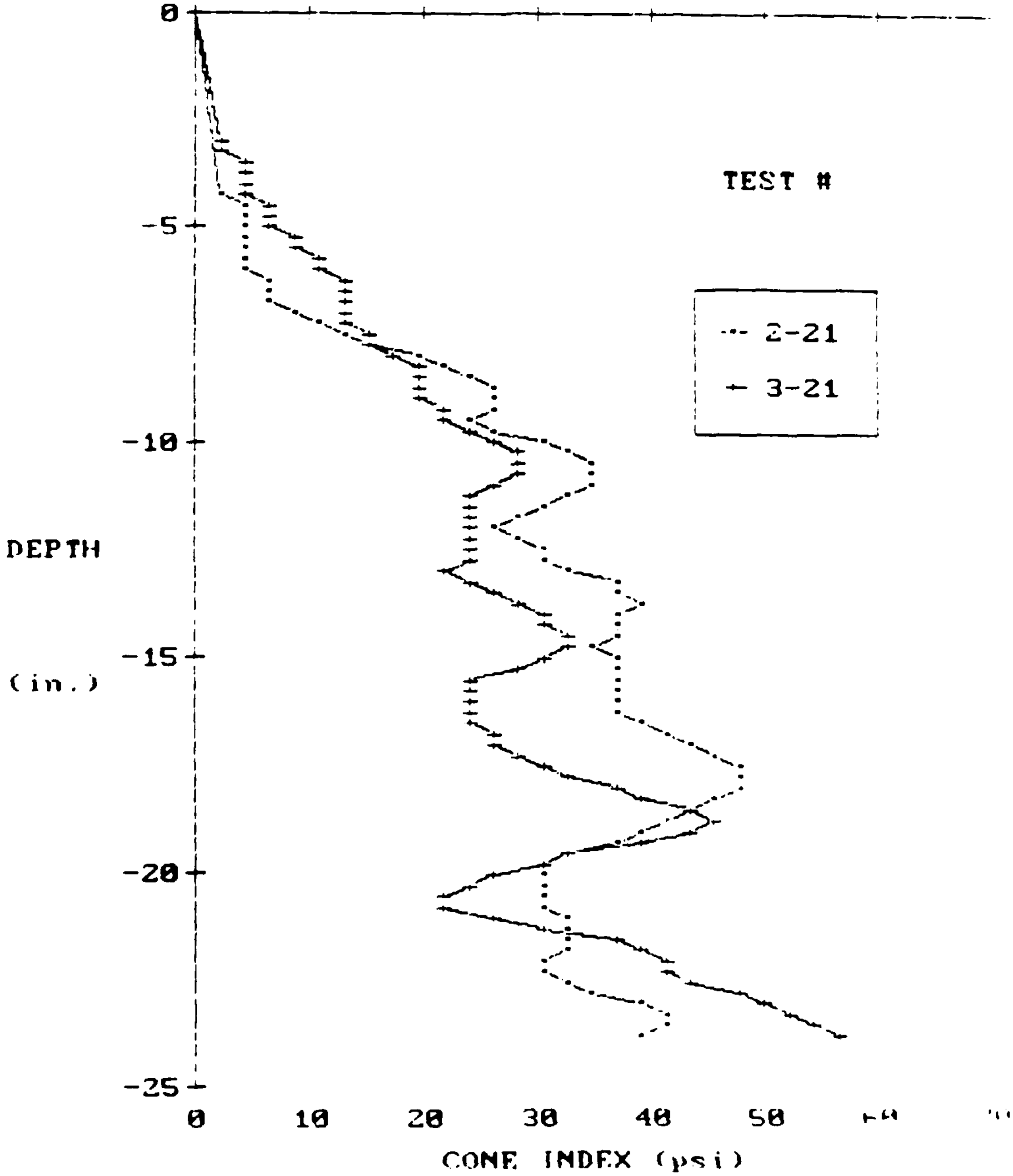

CONE INDEX VS. DEPTH
.2 SQUARE INCH CONE
CHATTAHOOCHEE RIVER SAND
DRY UNIT WEIGHT = 82.7 pcf
TESTS
1-19
2-19
3-19
DEPTH (in.)
0
-5
-10
-15
-20
-25
0
5
10
15
20
CONE INDEX (psi)

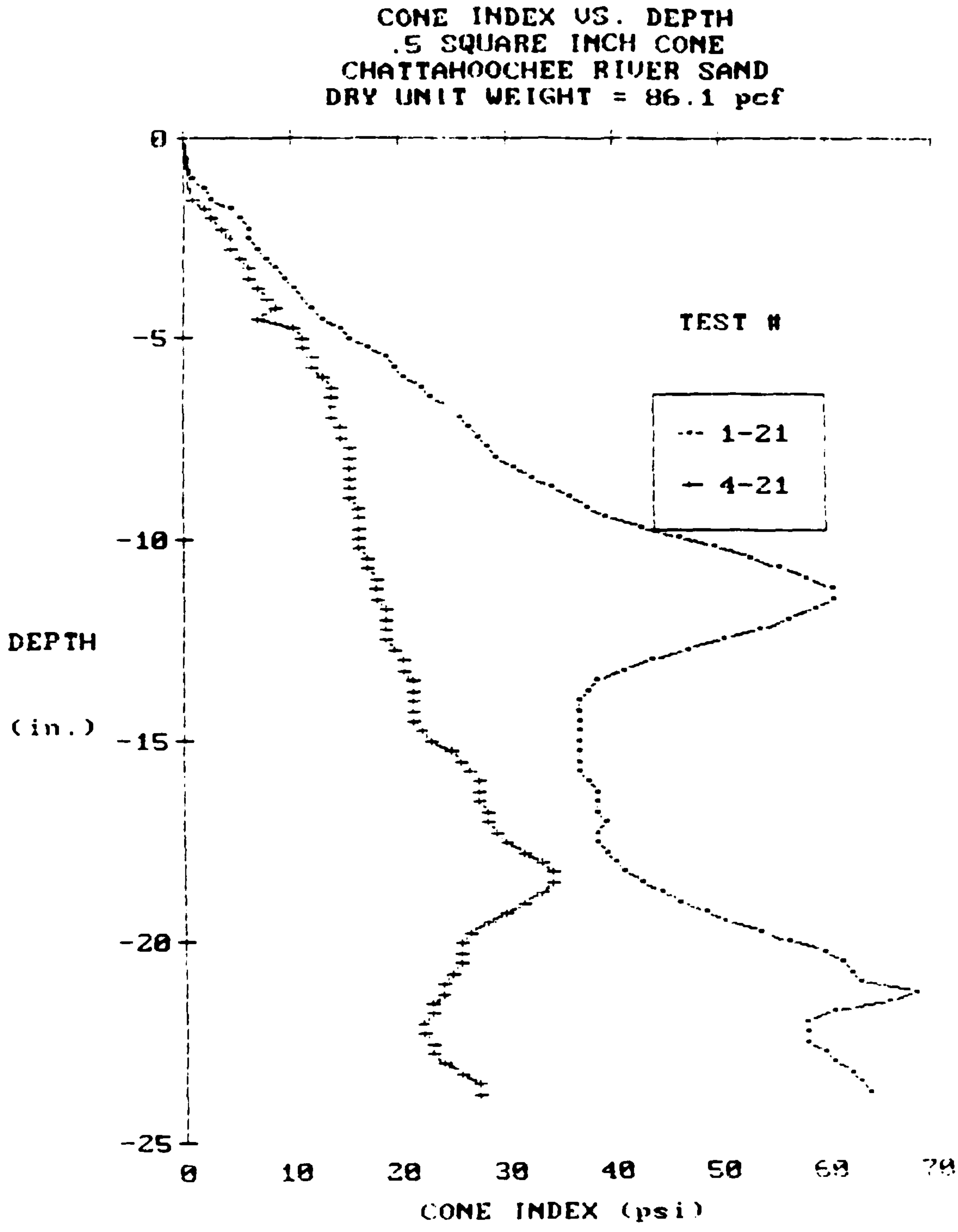

CONE INDEX VS. DEPTH
.2 SQUARE INCH CONE
CHATTAHOOCHEE RIVER SAND
DRY UNIT WEIGHT = 82.7 pcf
TEST#
1-19
4-19
DEPTH (in.)
0
-5
-10
-15
-20
-25
0
5
10
15
20
CONE INDEX (psi)


CONE INDEX VS. DEPTH
.2 SQUARE INCH CONE
CHATTAHOOCHEE RIVER SAND
DRY UNIT WEIGHT = 87.9 pcf
TEST #
1-01
2-01
3-01
4-01
DEPTH
(in.)
0
-5
-10
-15
-20
-25
0
10
20
30
40
50
60
CONE INDEX (psi)

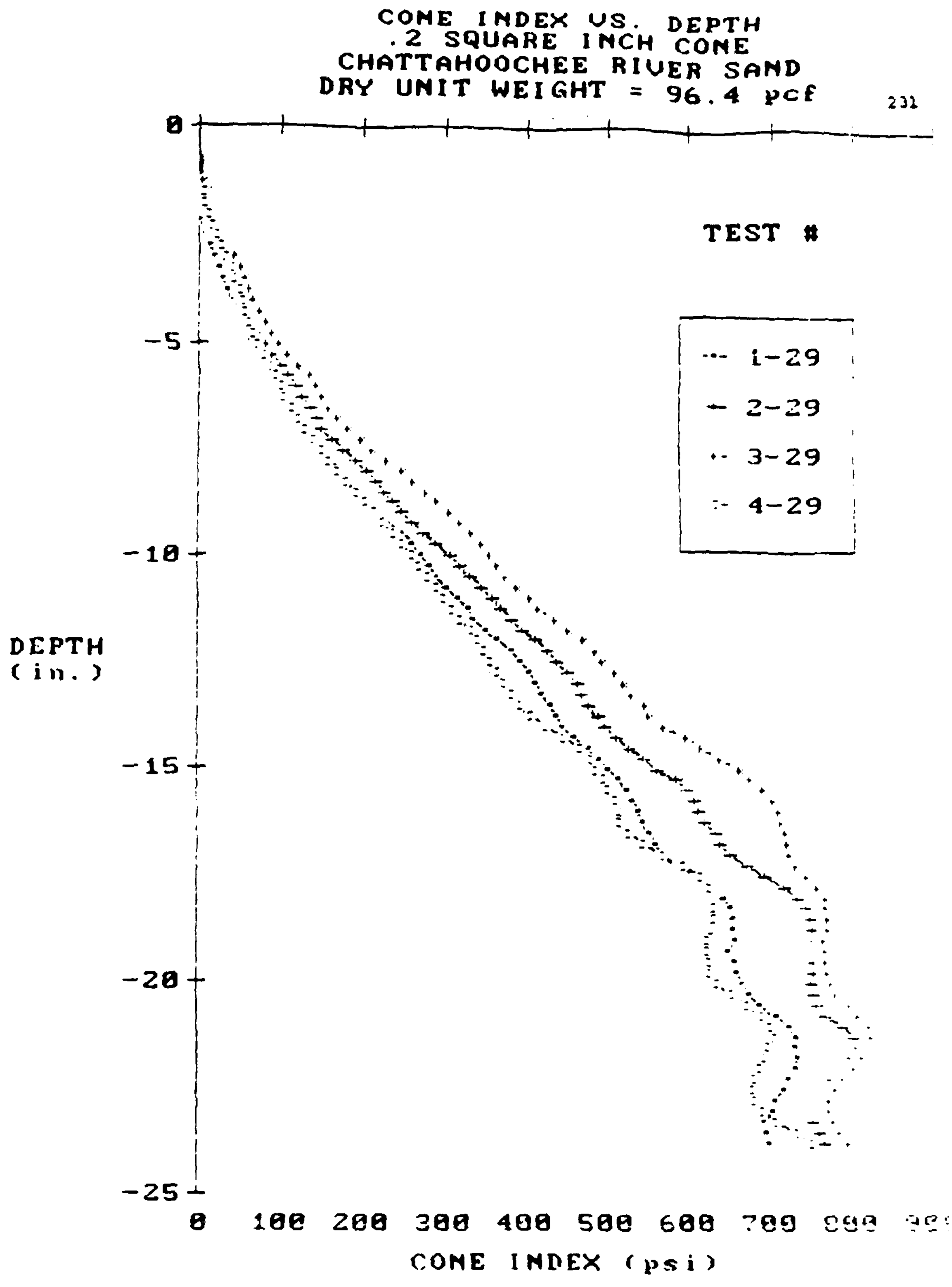

CONE INDEX VS. DEPTH
.2 SQUARE INCH CONE
CHATTAHOOCHEE RIVER SAND
DRY UNIT WEIGHT = 87.9 pcf
TEST #
1-01
4-01
DEPTH
(in.)
0
-5
-10
-15
-20
-25
0
10
20
30
40
50
60
70
CONE INDEX (psi)

CONE INDEX VS. DEPTH
.2 SQUARE INCH CONE
CHATTAHOOCHEE RIVER SAND
DRY UNIT WEIGHT = 86.1 pcf




CONE INDEX VS. DEPTH
.5 SQUARE INCH CONE
CHATTAHOOCHEE RIVER SAND
DRY UNIT WEIGHT = 86.1 pcf
TEST #
1-21
4-21
DEPTH
(in.)
0
-5
-10
-15
-20
-25
0
10
20
30
40
50
60
70
CONE INDEX (psi)

231



CONE INDEX VS. DEPTH
.2 SQUARE INCH CONE
CHATTAHOOCHEE RIVER SAND
DRY UNIT WEIGHT = 96.4 pcf
TEST #
1-29
2-29
3-29
4-29
DEPTH (in.)
0
-5
-10
-15
-20
-25
0
100
200
300
400
500
600
700
CONE INDEX (psi)

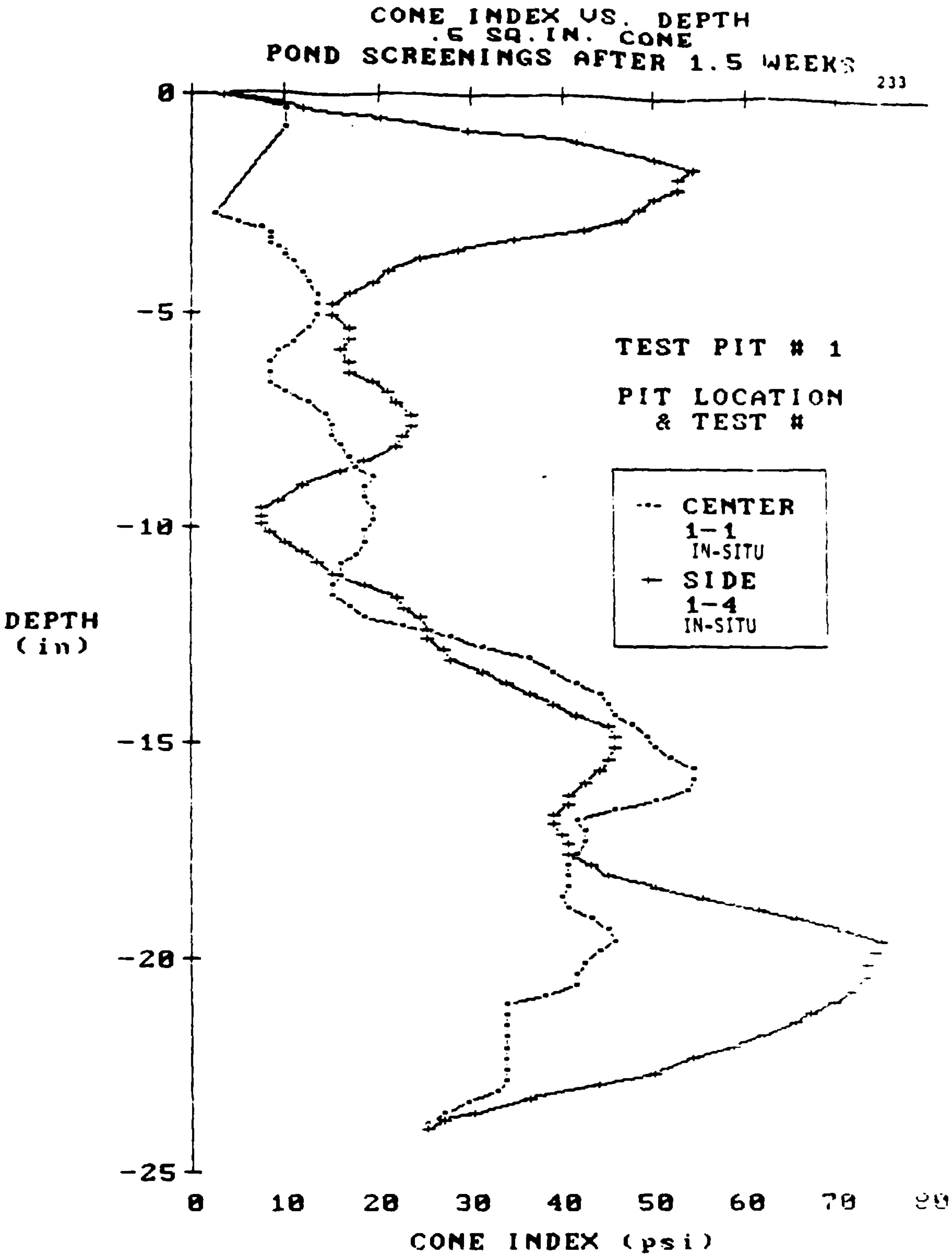
APPENDIX C

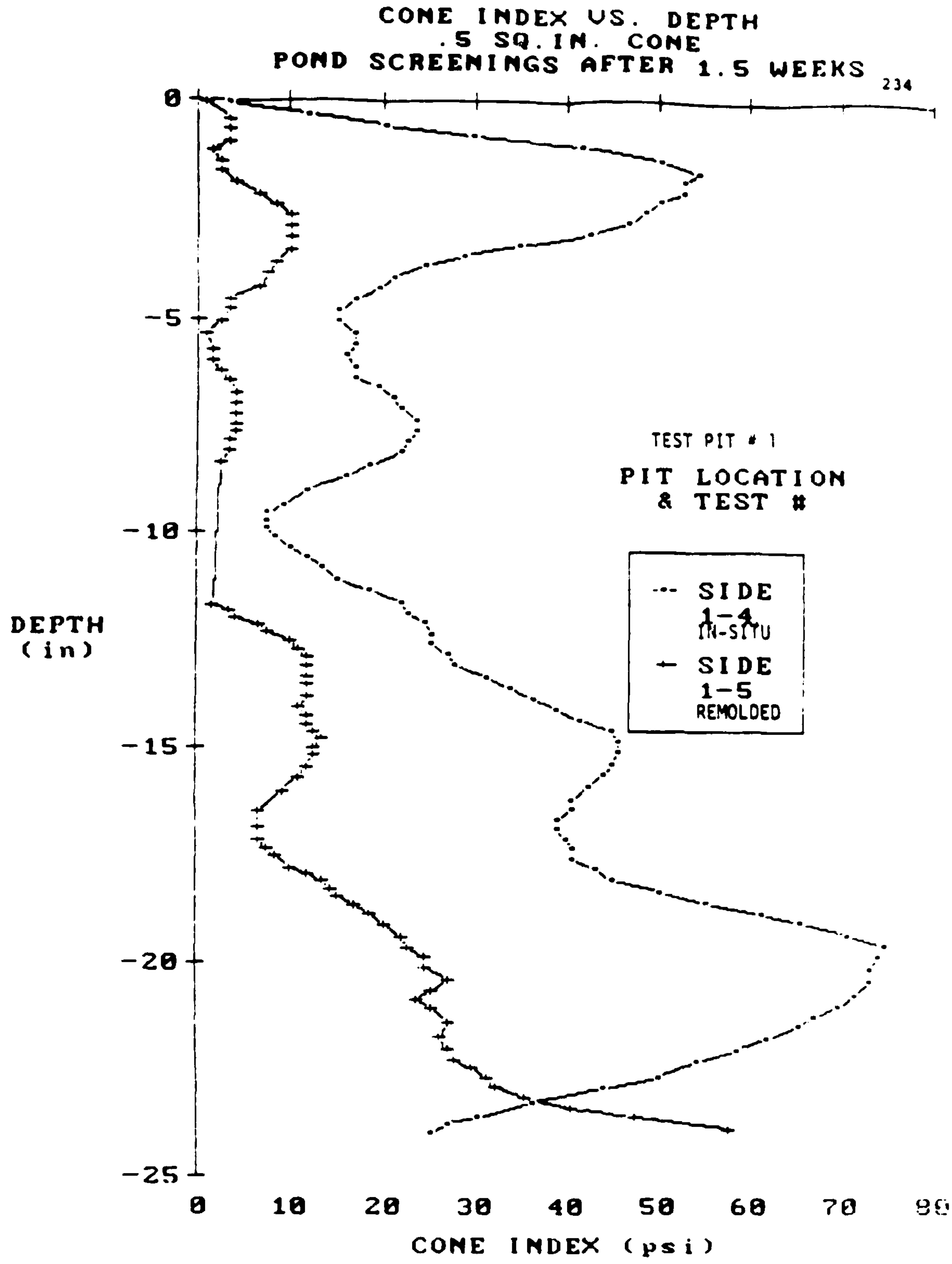
POND SCREENING SAMPLE

AUTOMATED MILITARY CONE PENETROMETER

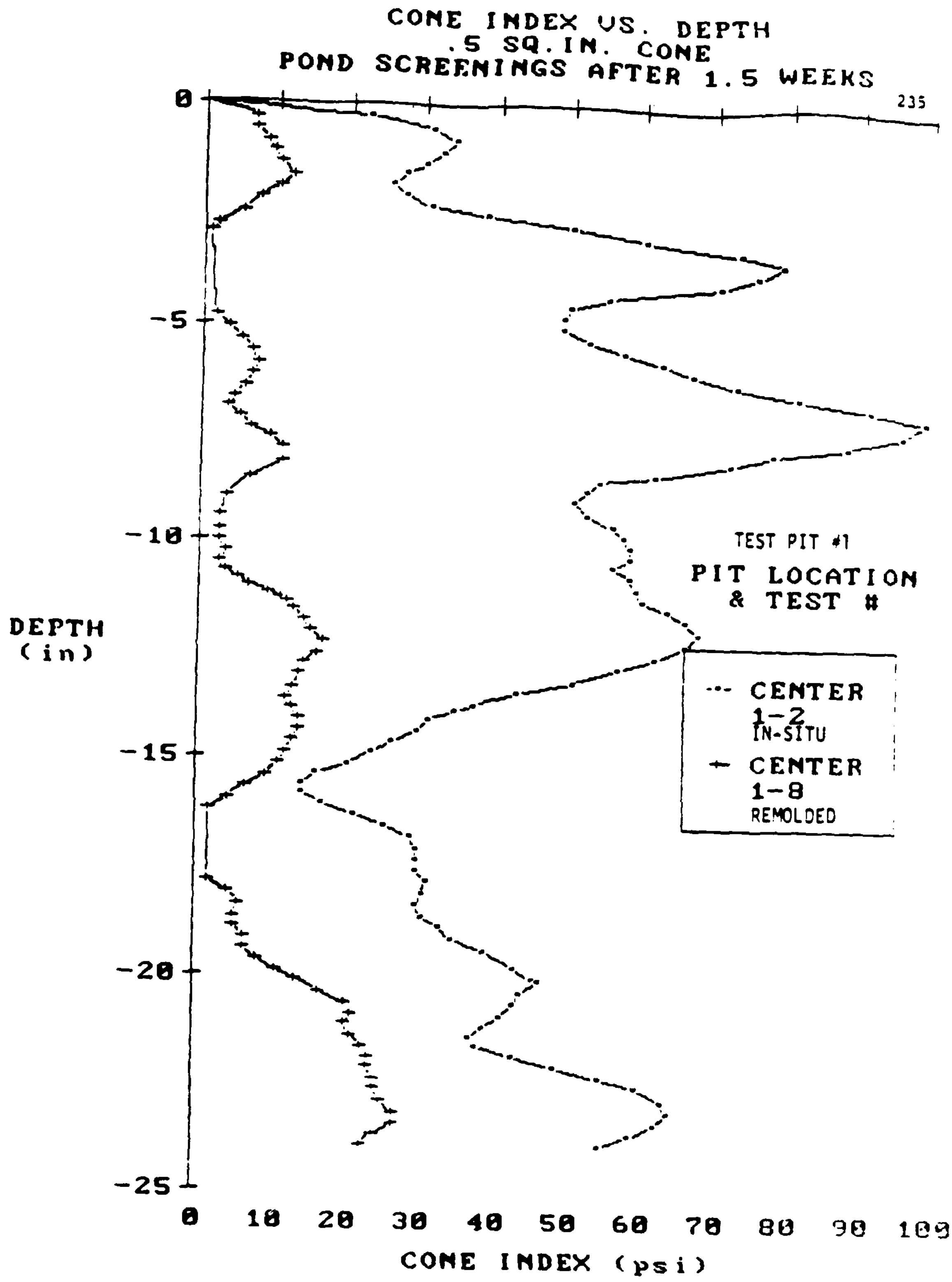
VULCAN QUARRY

KENNESAW, GEORGIA

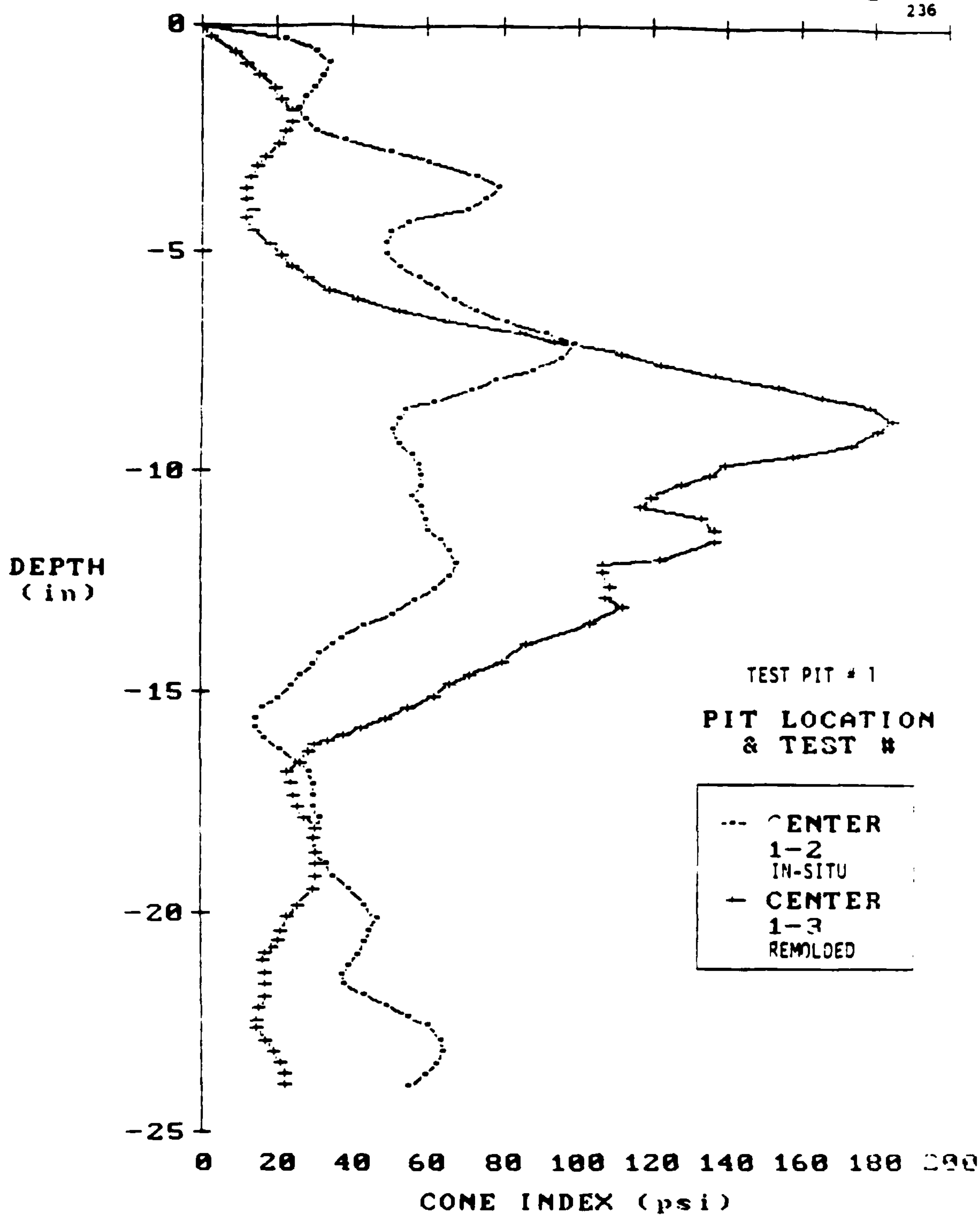

CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 1.5 WEEKS
233
TEST PIT # 1
PIT LOCATION
& TEST #
CENTER
1-1
IN-SITU
SIDE
1-4
IN-SITU
DEPTH
(in)
0
-5
-10
-15
-20
-25
0
10
20
30
40
50
60
70
80
CONE INDEX (psi)

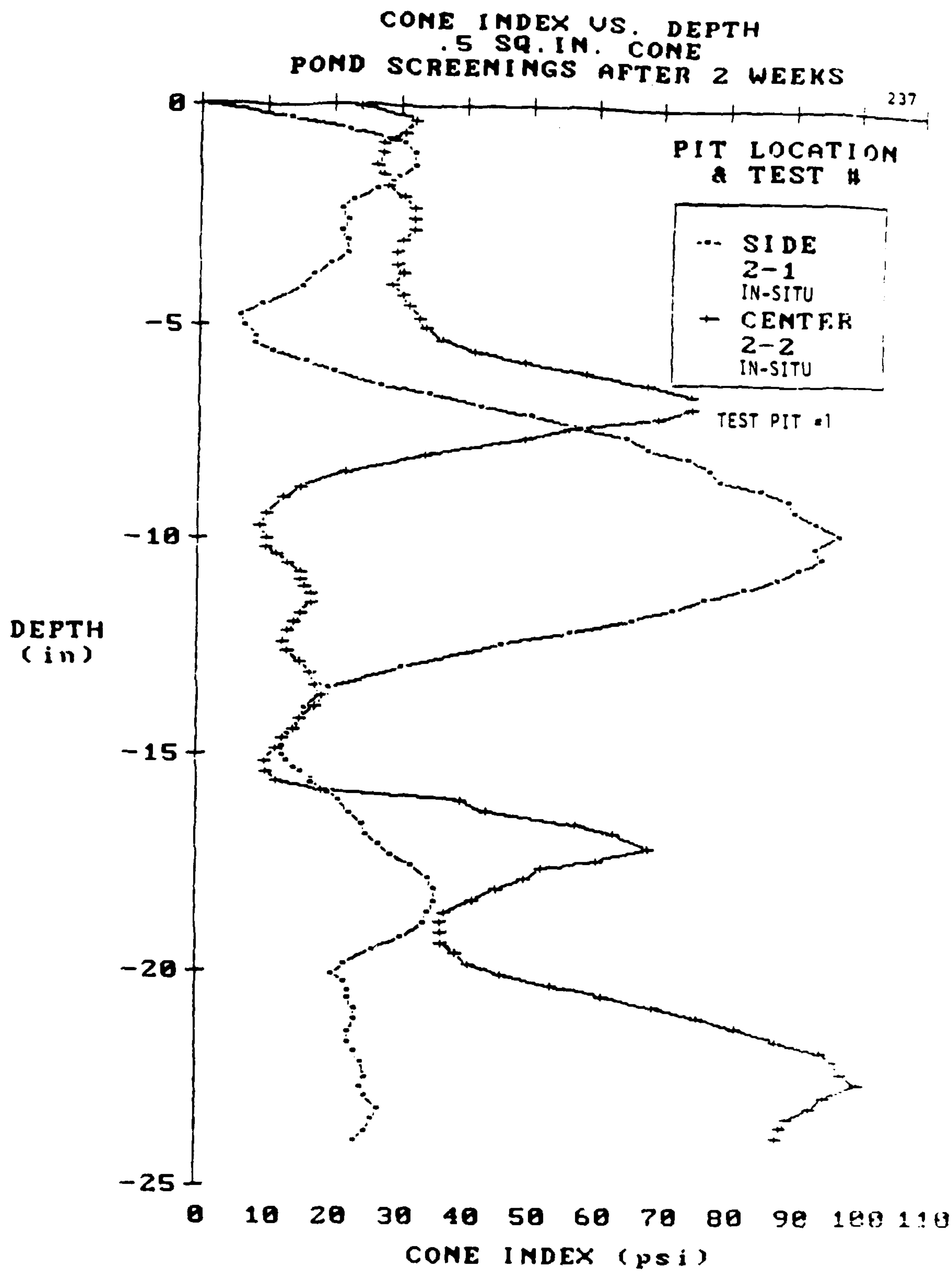


CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 1.5 WEEKS
234
0
-5
-10
-15
-20
-25
DEPTH (in)
TEST PIT # 1
PIT LOCATION & TEST #
SIDE 1-4 IN-SITU
SIDE 1-5 REMOLDED
0
10
20
30
40
50
60
70
80
CONE INDEX (psi)

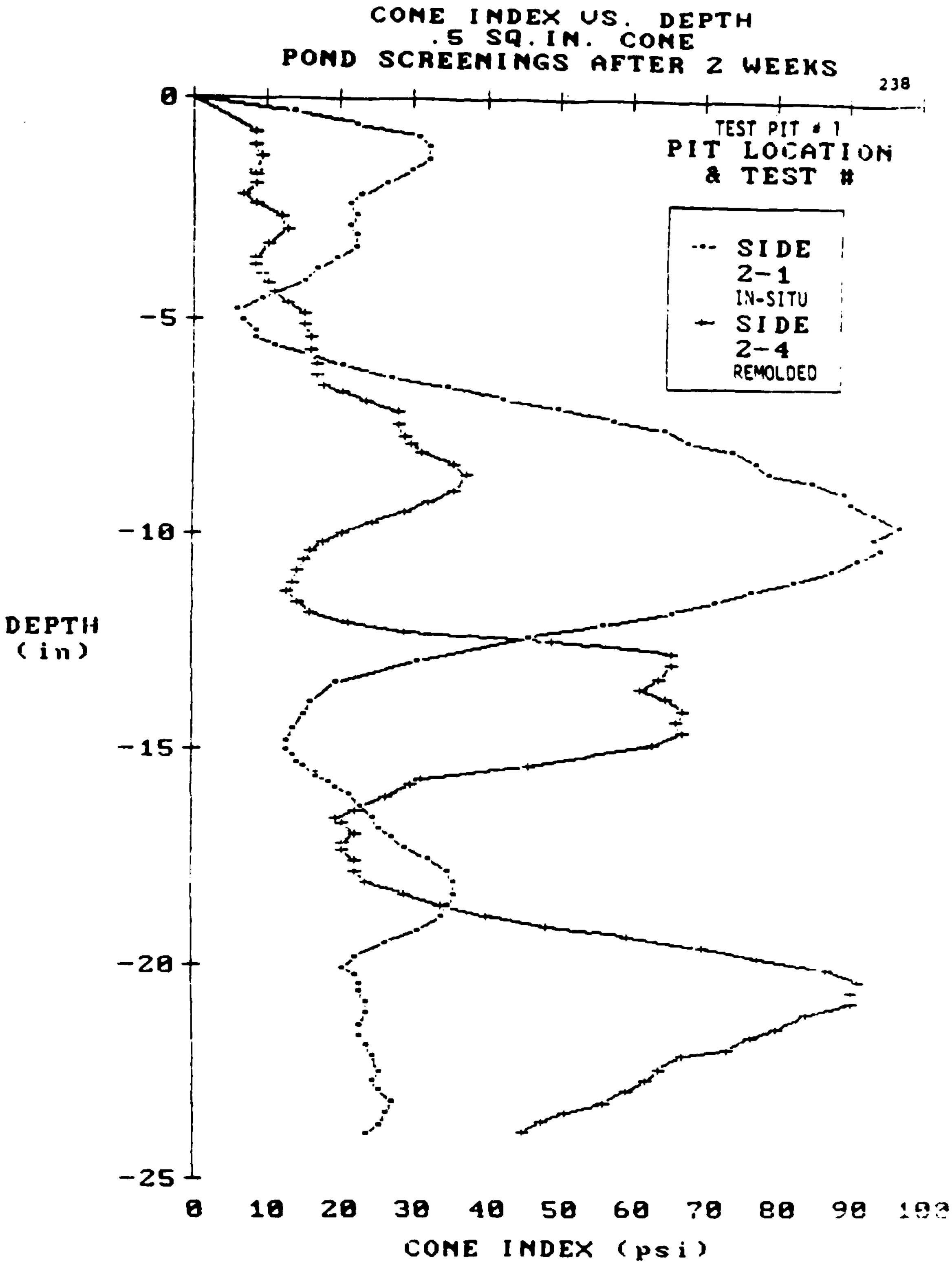

CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 1.5 WEEKS
235
0
-5
-10
-15
-20
-25
DEPTH
(in)
TEST PIT #1
PIT LOCATION
& TEST #
CENTER
1-2
IN-SITU
CENTER
1-8
REMOLDED
0
10
20
30
40
50
60
70
80
90
100
CONE INDEX (psi)

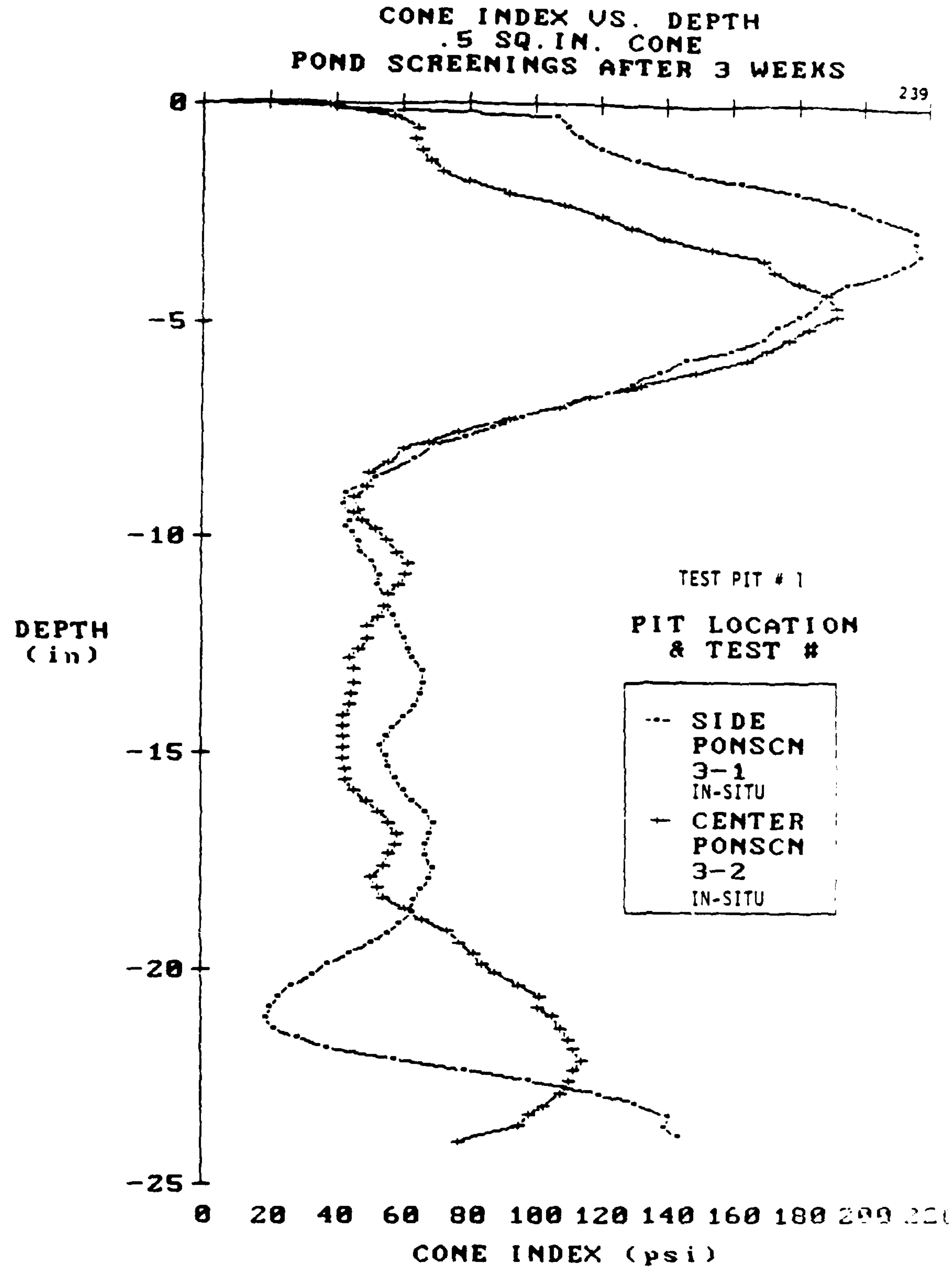
CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 1.5 WEEKS



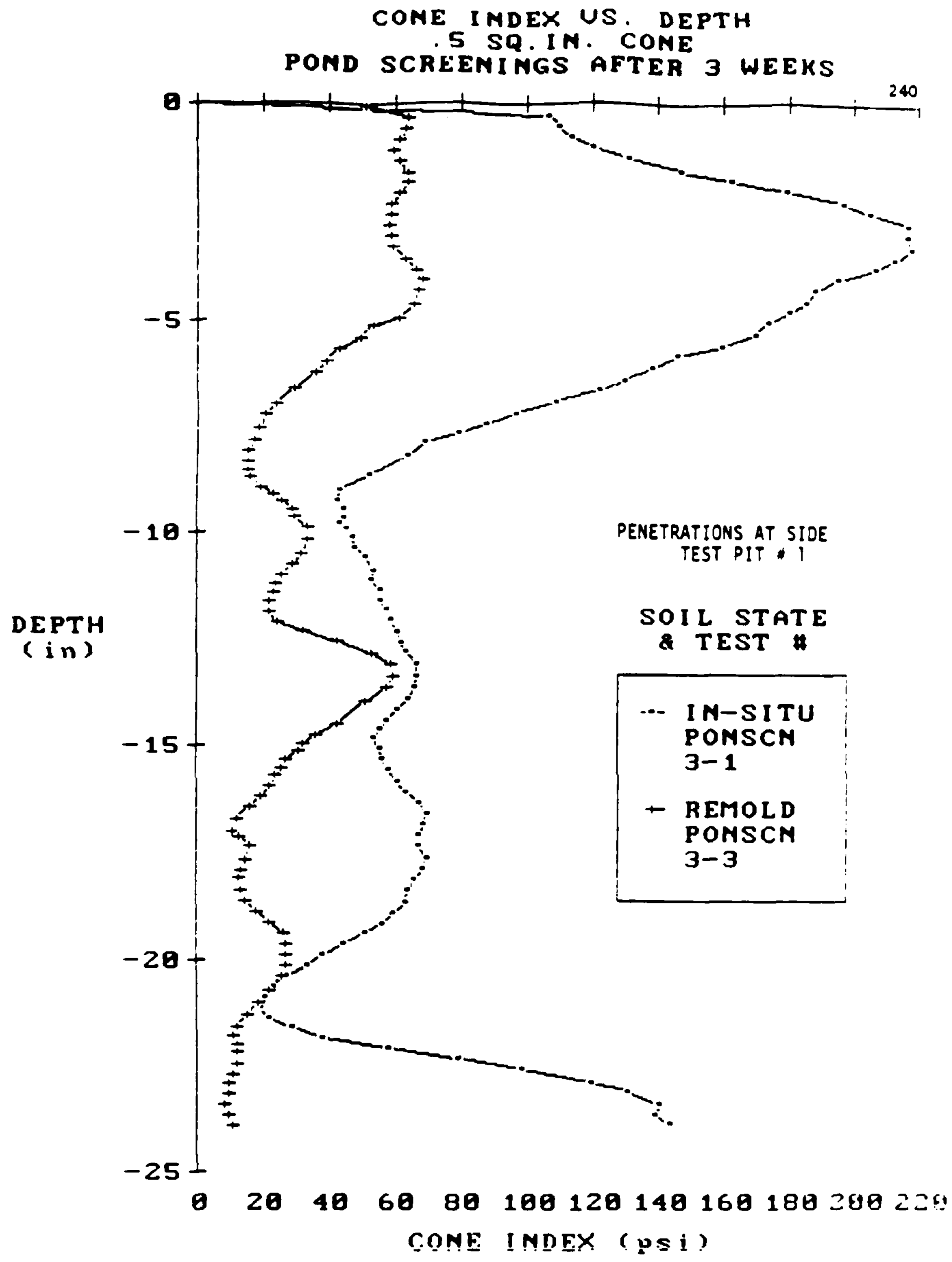


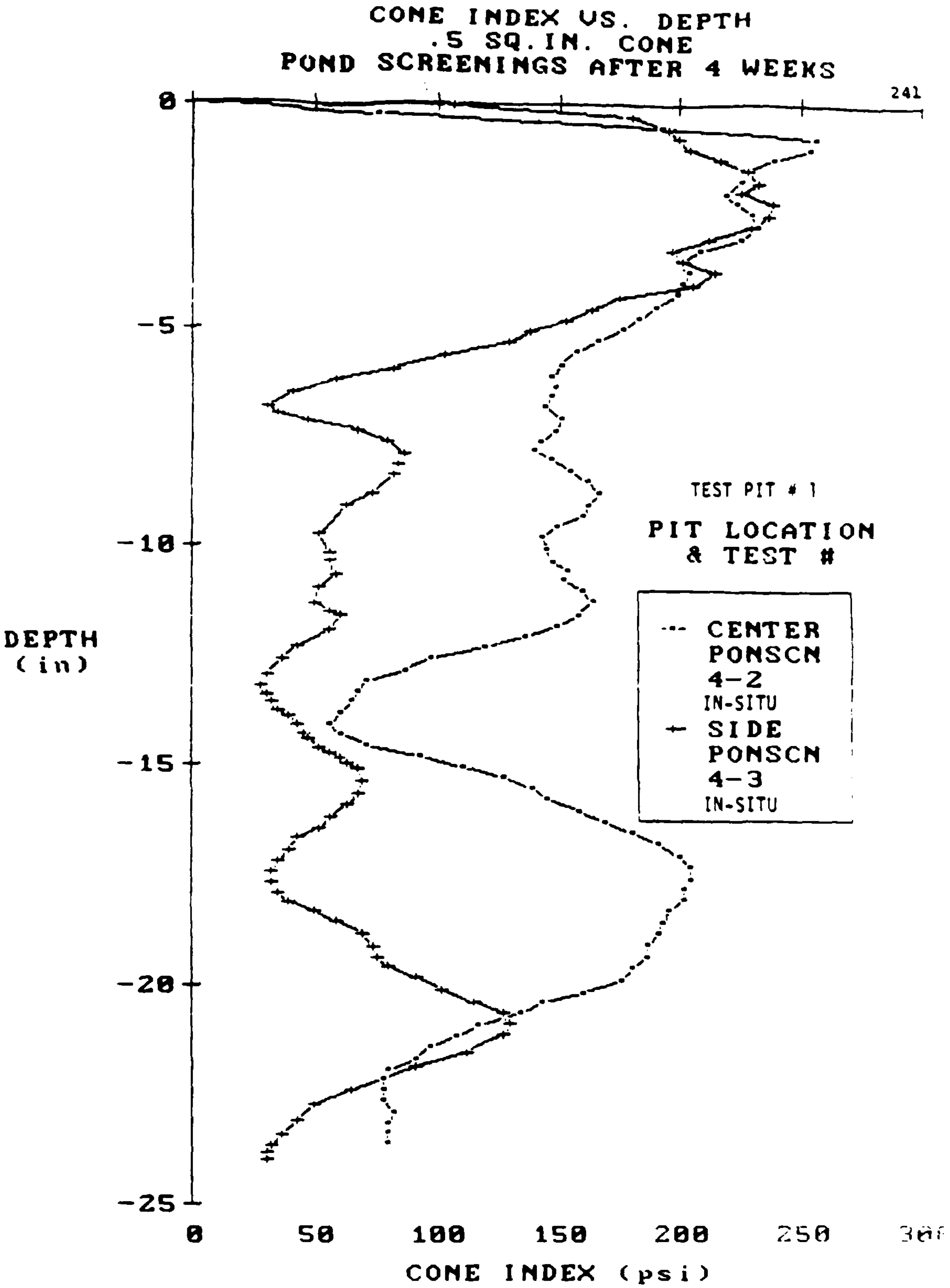
CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 2 WEEKS
237
PIT LOCATION
& TEST #
SIDE
2-1
IN-SITU
CENTER
2-2
IN-SITU
TEST PIT #1
DEPTH
(in)
0
-5
-10
-15
-20
-25
0 10 20 30 40 50 60 70 80 90 100 110
CONE INDEX (psi)


CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 2 WEEKS
238
TEST PIT # 1
PIT LOCATION
& TEST #
SIDE
2-1
IN-SITU
SIDE
2-4
REMOLDED
DEPTH
(in)
0
-5
-10
-15
-20
-25
0 10 20 30 40 50 60 70 80 90 100
CONE INDEX (psi)

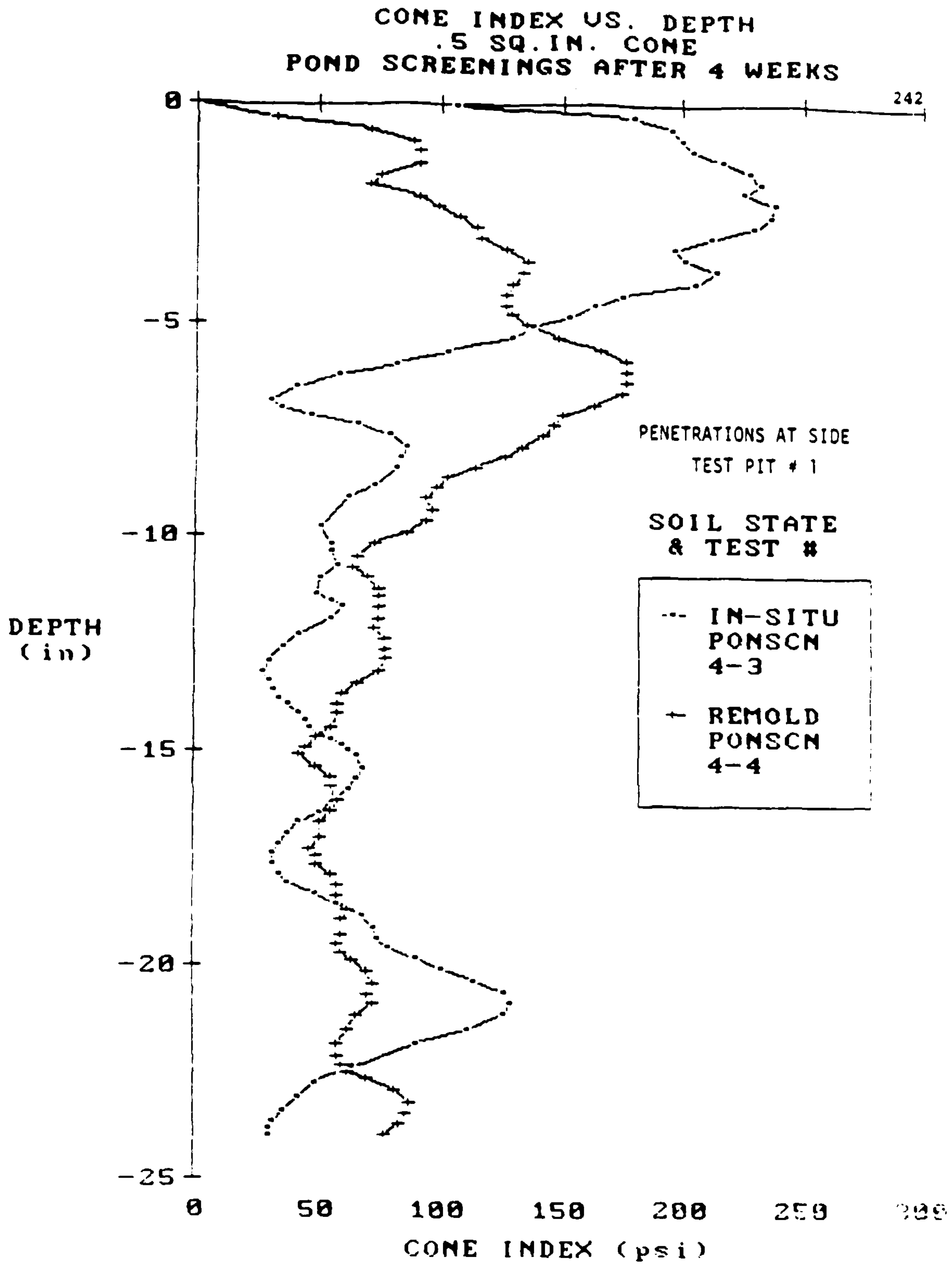


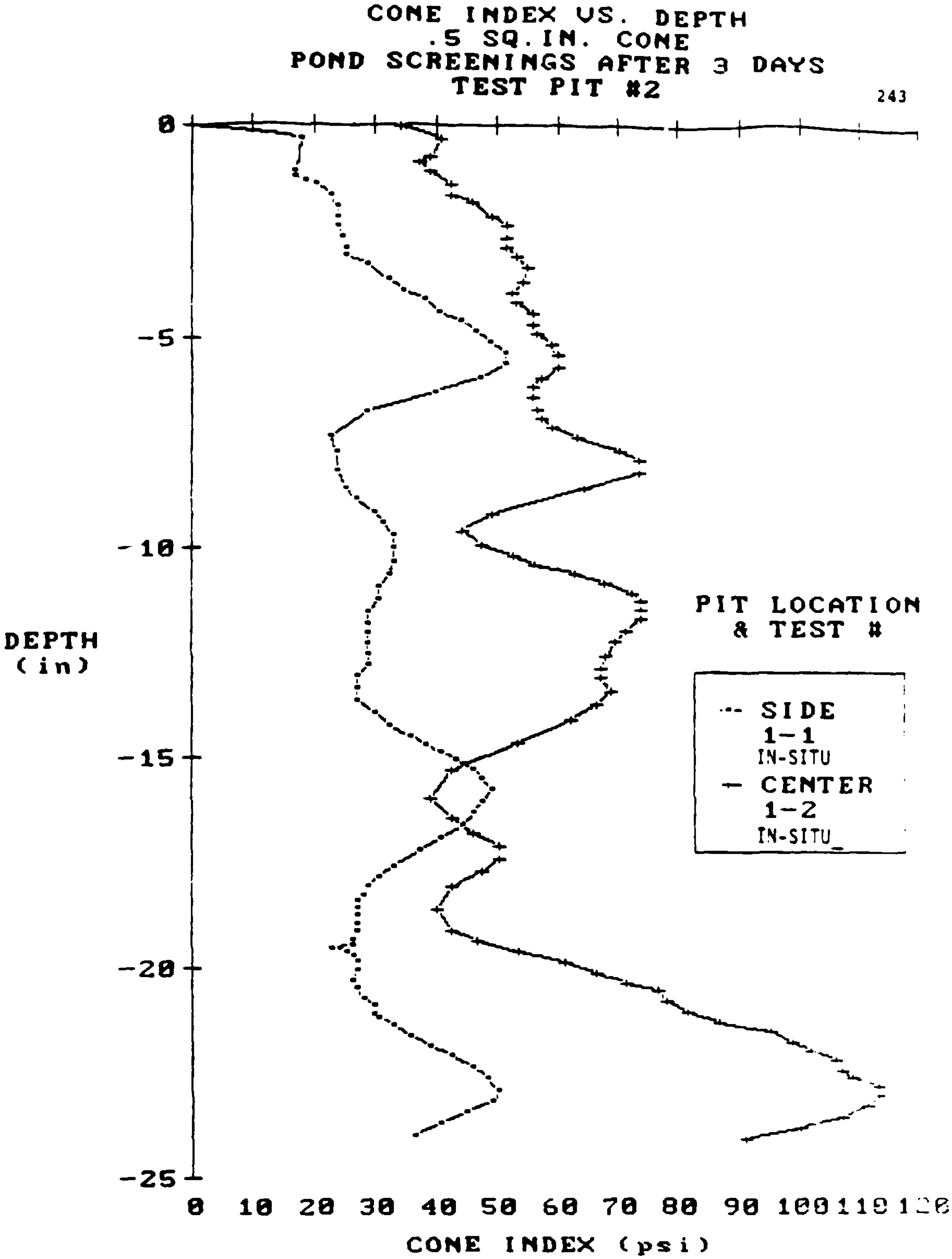
CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 3 WEEKS
239
DEPTH (in)
0
-5
-10
-15
-20
-25
TEST PIT # 1
PIT LOCATION & TEST #
SIDE PONSCN 3-1 IN-SITU
CENTER PONSCN 3-2 IN-SITU
0 20 40 60 80 100 120 140 160 180
CONE INDEX (psi)


CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 3 WEEKS
240
0
-5
-10
-15
-20
-25
DEPTH
(in)
0 20 40 60 80 100 120 140 160 180 200 220
CONE INDEX (psi)
PENETRATIONS AT SIDE
TEST PIT # 1
SOIL STATE
& TEST #
IN-SITU
PONSCN
3-1
REMOLD
PONSCN
3-3

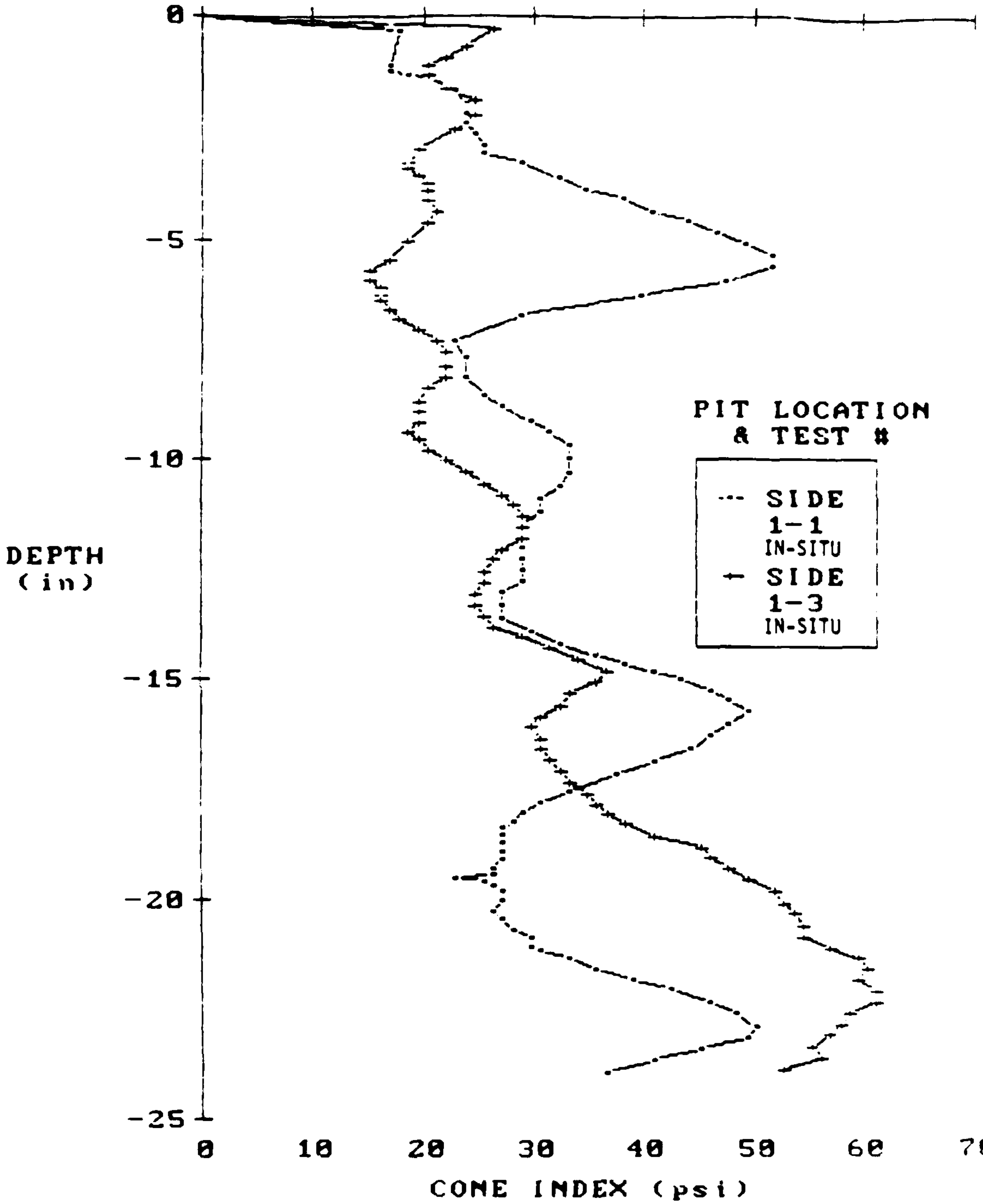


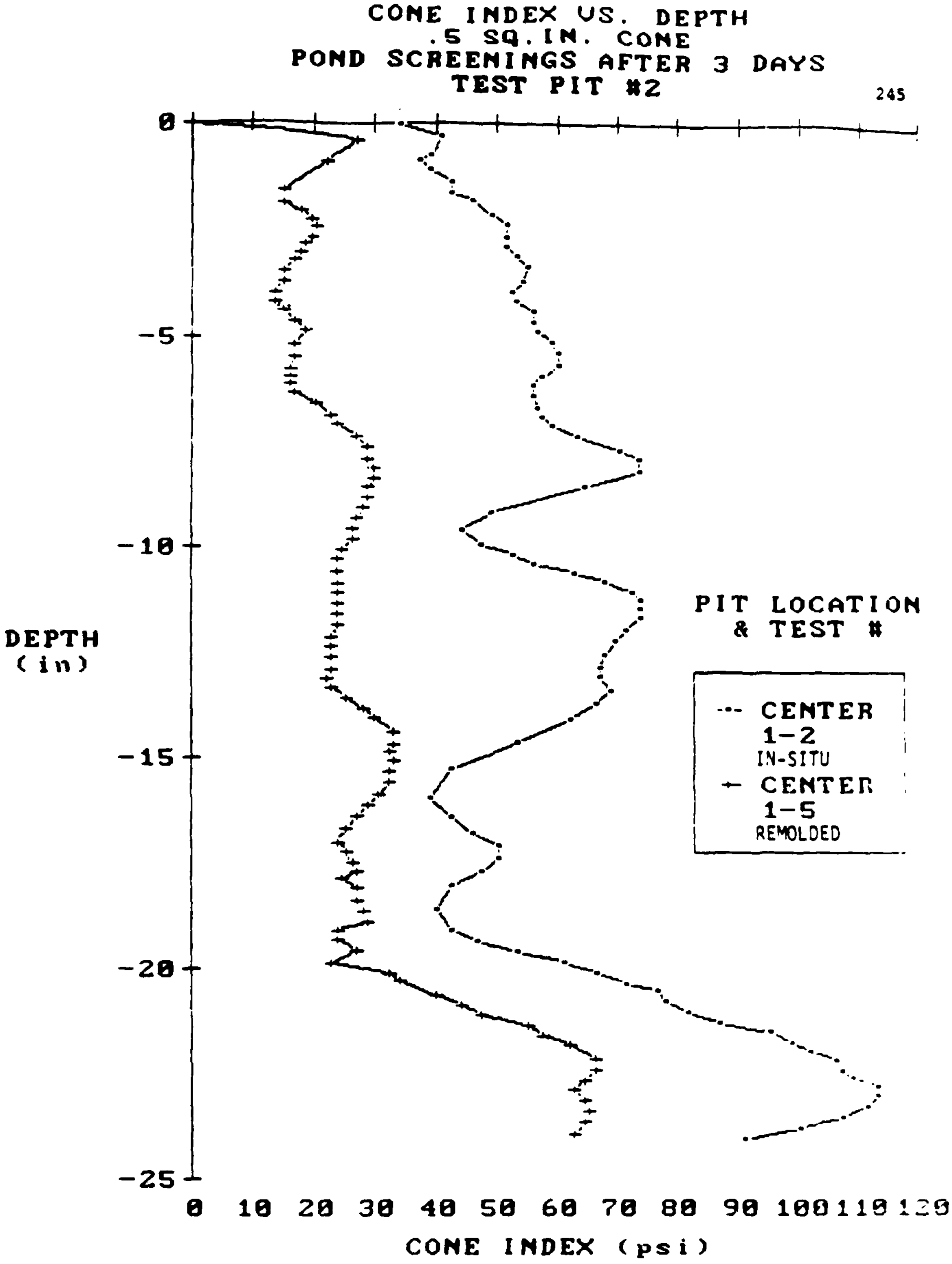
CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 4 WEEKS
241
0
-5
-10
-15
-20
-25
DEPTH (in)
TEST PIT # 1
PIT LOCATION & TEST #
CENTER PONSCN 4-2 IN-SITU
SIDE PONSCN 4-3 IN-SITU
0
50
100
150
200
250
CONE INDEX (psi)


CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 4 WEEKS
242
0
-5
-10
-15
-20
-25
DEPTH
(in)
PENETRATIONS AT SIDE
TEST PIT # 1
SOIL STATE
& TEST #
IN-SITU
PONSCN
4-3
REMOLD
PONSCN
4-4
0
50
100
150
200
250
300
CONE INDEX (psi)

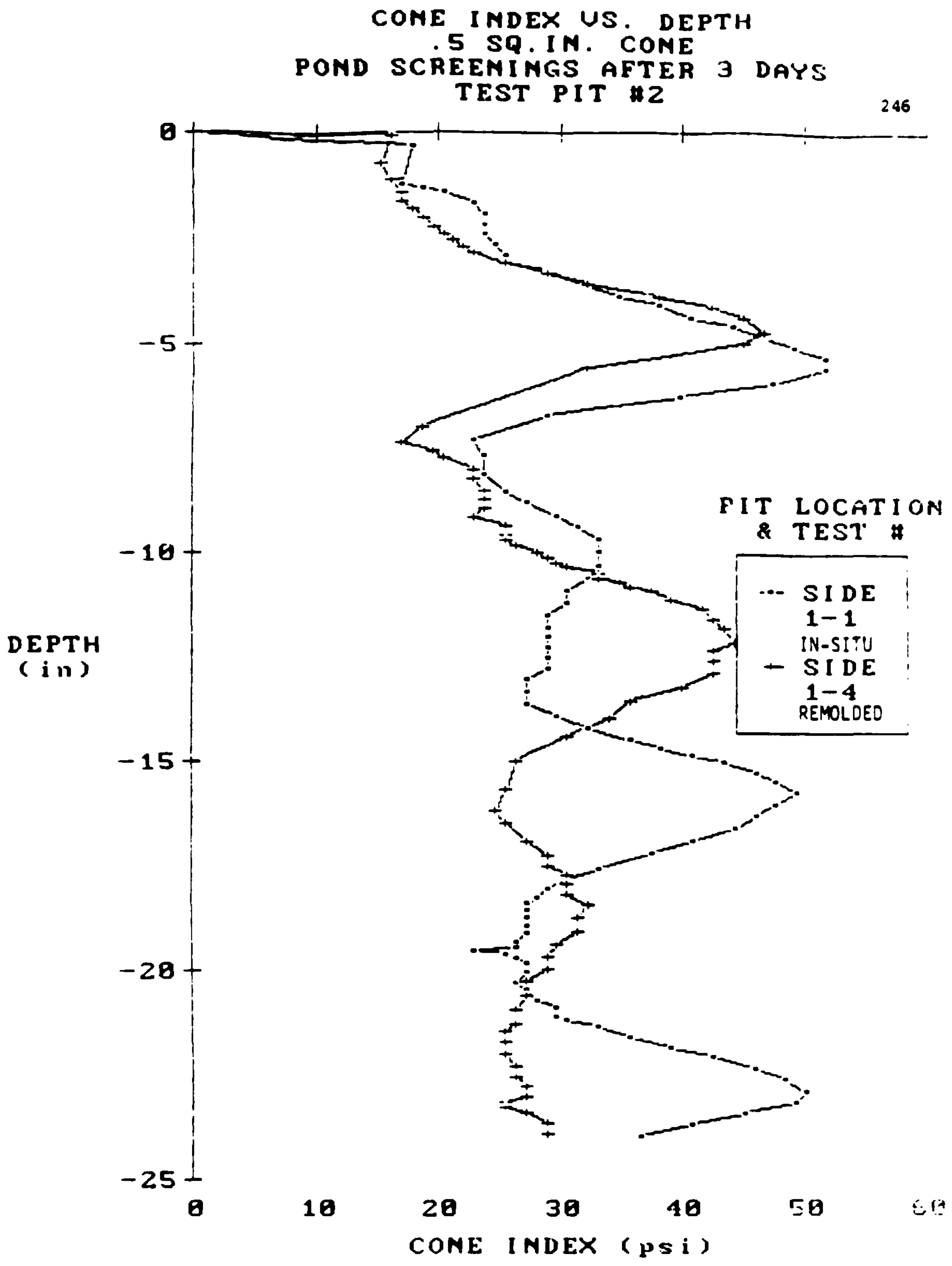

CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 3 DAYS
TEST PIT #2
0
-5
-10
-15
-20
-25
DEPTH (in)
PIT LOCATION & TEST #
SIDE 1-1 IN-SITU
CENTER 1-2 IN-SITU
0 10 20 30 40 50 60 70 80 90 100 110 120
CONE INDEX (psi)

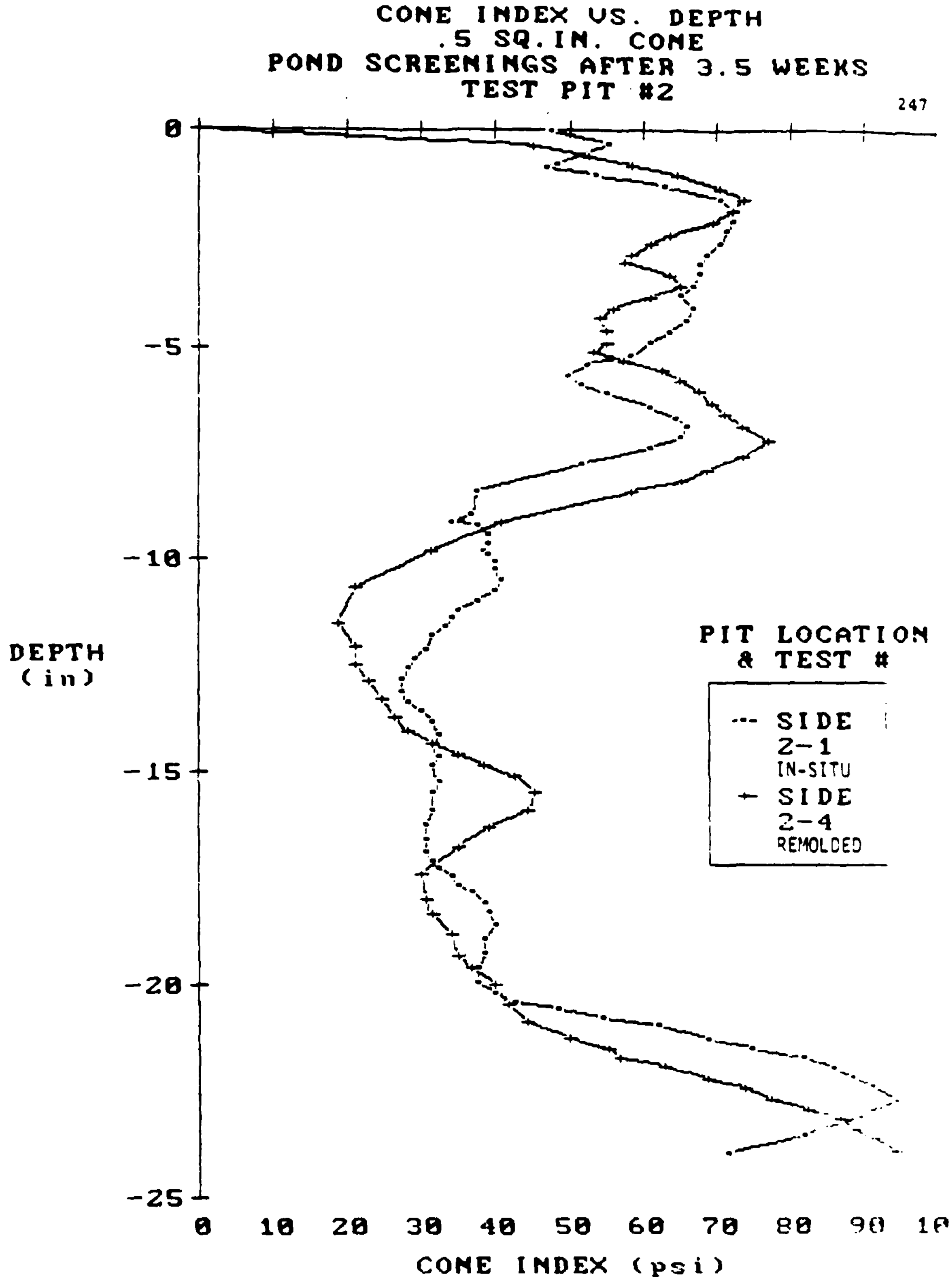
CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 3 DAYS
TEST PIT #2




CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 3 DAYS
TEST PIT #2
DEPTH (in)
0
-5
-10
-15
-20
-25
0 10 20 30 40 50 60 70 80 90 100 110 120
CONE INDEX (psi)
PIT LOCATION & TEST #
CENTER 1-2 IN-SITU
CENTER 1-5 REMOLDED

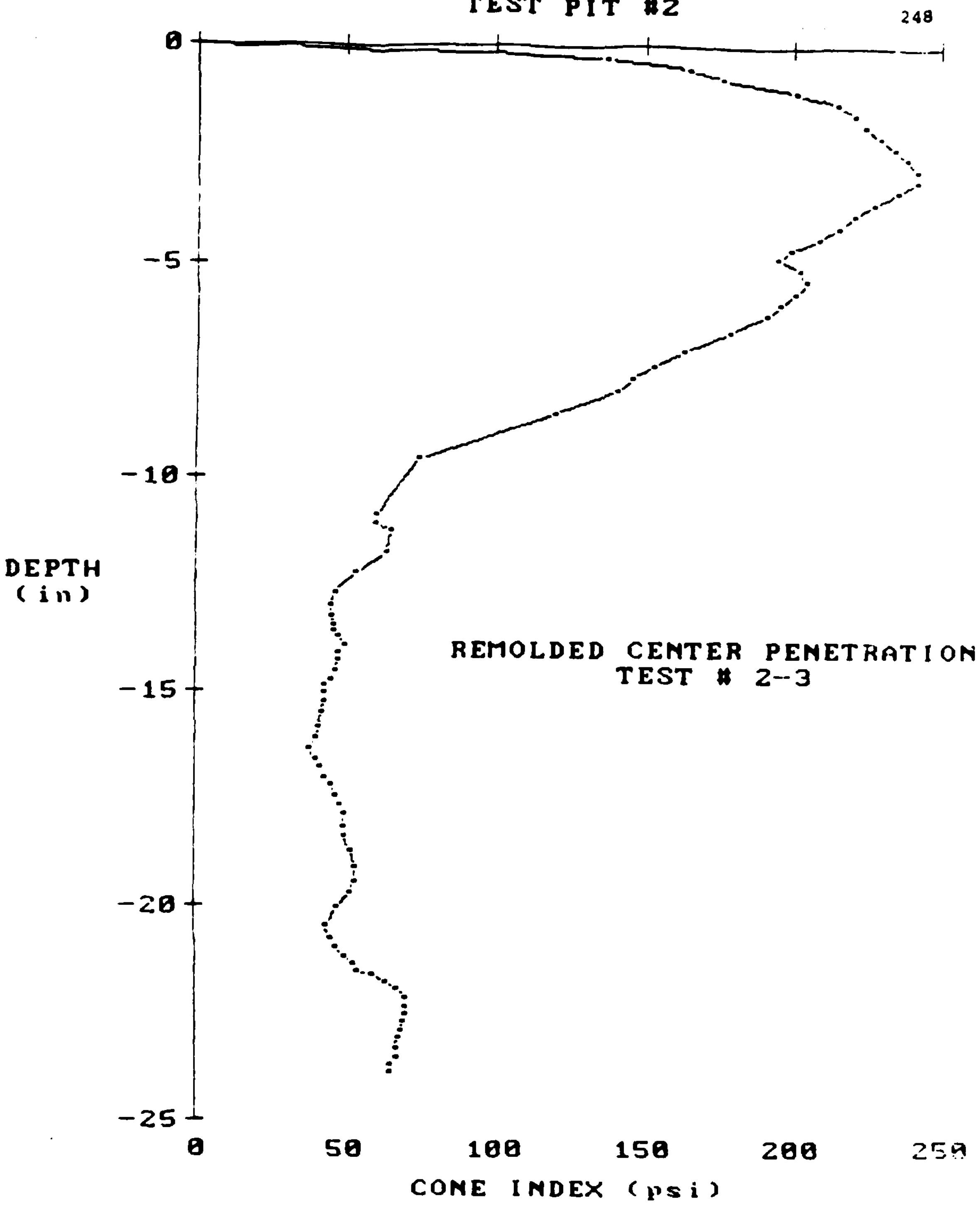
246


CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 3 DAYS
TEST PIT #2
0
-5
-10
-15
-20
-25
DEPTH
(in)
0
10
20
30
40
50
60
CONE INDEX (psi)
PIT LOCATION
& TEST #
SIDE
1-1
IN-SITU
SIDE
1-4
REMOLDED



CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 3.5 WEEKS
TEST PIT #2
247
0
-5
-10
-15
-20
-25
DEPTH
(in)
PIT LOCATION
& TEST #
SIDE
2-1
IN-SITU
SIDE
2-4
REMOLDED
0 10 20 30 40 50 60 70 80 90 10
CONE INDEX (psi)

CONE INDEX VS. DEPTH
.5 SQ.IN. CONE
POND SCREENINGS AFTER 3.5 WEEKS
TEST PIT #2



APPENDIX D

AUTOMATED MILITARY CONE PENETROMETER

COMPUTER PROGRAM

```
1 DIM(1ØØØ,1ØØØØ)              :REM 1ØØØ ELEMENTS IN ARRAY;1ØØØØ IN DATA FILE
4 A=Ø                          :REM A= NUMBER OF SAMPLES IN THE SAMPLE AVERAGE
5 A=Ø                          :REM LOOP VARAIBLE IN THE STORE ROUTINE
6 B=Ø                          :REM B= LOOP VARAIBLE IN THE STORE ROUTINE
8 C=Ø                          :REM C= LOOP VARAIBLE IN THE STORE ROUTINE
1Ø D=Ø                         :REM D= AUTO INCREMENTING VARIABLE (DATA TABLE)
12 E=Ø                         :REM E=DUMP
14 F=Ø                         :REM F= STORE
16 G=Ø                         :REM G=DISPLAY
18 H=Ø                         :REM H=DISPLAY
2Ø I=Ø                         :REM I=DISPLAY
22 J=Ø                         :REM J=DISPLAY
24 K=Ø                         :REM K=DISPLAY
26 L=Ø                         :REM L=COMMON VARIABLE
28 M=Ø                         :REM M=MODE OF OPERATION
3Ø N=Ø                         :REM N=TEST NUMBER
32 O=Ø                         :REM O=INPUT TEXT VARIABLE;USABLE
34 P=Ø                         :REM P=COMMON VARIABLE
36 Q=Ø                         :REM Q=COMMON VARIABLE
38 R=Ø                         :REM R=COMMON VARIABLE
4Ø S=Ø                         :REM S=NUMBER OF SAMPLES IN A PENETRATION
42 T=Ø                         :REM T=LAPSED TIME BETWEEN SAMPLES
44 V=Ø                         :REM V=DISPLAY WORD
46 W=Ø                         :REM W=TEST AREA
48 X=Ø                         :REM X=DISPLAY
5Ø Y=Ø                         :REM Y=COLLECT
52 Z=Ø                         :REM Z=COLLECT
54 ?=Ø                         :REM ?= TIMER
56 @(1)=138                    :REM @(1)=BASE OF THE CONE
58 @(2)=Ø                      :REM @(2)=BASE-.5*DEPTH INCREMENTS(FIRST READING)
6Ø @(3)=6                      :REM @(3)=DEPTH INCREMENTS(.248 INCHES)
62 @(4)=Ø                      :REM @(4)=LAST DEPTH+@(3)
64 @(5)=575+@(1)               :REM @(5)=DEPTH LIMIT
66 @(6)=Ø                      :REM @(6)=PRESENT LOCATION TO MARK TEST
68 @(7)=Ø                      :REM @(7)=TEMPORARY STORAGE FOR DATA POINTER (D)
7Ø @(8)=235                    :REM @(8)=DEFAULT SCALE FACTOR FOR LOAD CELL
72 @(9)=2393                   :REM @(9)=DEFAULT SCALE FACTOR FOR DEPTH
74 @(1Ø)=Ø                     :REM @(1Ø)=LOAD FOR DISPLAY
76 @(11)=1Ø2                   :REM @(11)=LOADCELL WITH NO LOAD
78 @(12)=99                    :REM @(12)=MAX NUMBER OF SAMPLES/TEST
8Ø REM                         :REM CHAN(Ø)=LOADCELL
82 REM                         :REM CHAN(1)=DISTANCE
84 @(2)=@(1)-(@(3)/2)          :REM
86 PSET 1Ø
99 REM  #################################################################
1ØØ REM ################# MAIN PROGRAM###################################
1Ø1 REM ##################### CLEAR ARRAY ##################################
11Ø REM
115 PSET 1Ø
12Ø FOR X=1ØØ TO 9ØØ
13Ø @(X)=Ø
14Ø NEXT X
145 PCLR 1Ø
15Ø REM
```

```
170 REM ######################## MODE SELECTION ############################
300 IF PIN(1)=0 PCLR 13:GOTO 300 :REM STOP MODE
310 GOSUB 500                    :REM SELECT THE MODE
330 GOSUB 800                    :REM GET  TEST  AREA
340 IF M=1 GOSUB 8000            :REM      MARK  MODE
350 IF M=2 GOSUB 9000            :REM      DUMP  MODE
360 IF M=3 GOSUB 3000            :REM     CLEAR  MODE
370 IF M=4 GOSUB 4000            :REM    MONITOR MODE
380 IF M=5 GOSUB 5000            :REM     1 INCH MODE
390 IF M=6 GOSUB 5000            :REM    .5 INCH MODE
400 IF M=7 GOSUB 5000            :REM    .2 INCH MODE
410 IF M=8 GOSUB 6000            :REM    CALIBRATE MODE
420 GOTO 300                     :REM     START  OVER
500 REM ##################################################################
510 REM **************** SUBROUTINE TO CHECK MODES  *********************
520 REM
530 M=0
540 PCLR 6,7,8
550 X=PIN(9):IF X=0 M=3       :REM   CLEAR  MODE
560 REM
570 PCLR 6,7,8:PSET 6
580 X=PIN(9):IF X=0 M=6       :REM  .5 INCH  MODE
590 REM
630 PCLR 6,7,8:PSET 6,7
640 X=PIN(9):IF X=0 M=5       :REM 1 INCH MODE
650 REM
660 PCLR 6,7,8:PSET 8
670 X=PIN(9):IF X=0 M=7      :REM  .2 INCH MODE
680 REM
690 PCLR 6,7,8:PSET 6,8
700 X=PIN(9):IF X=0 M=2      :REM  DUMP MODE
705 REM
710 PCLR 6,7,8:PSET 7,8
720 X=PIN(9):IF X=0 M=8      :REM  CALIBRATE MODE
725 REM
730 PCLR 6,7,8:PSET 6,7,8
740 X=PIN(9):IF X=0 M=1      :REM MARK MODE
750 IF M=0 GOTO 500          :REM NO SELECTION
760 RETURN
800 REM ************ SUBROUTINE TO READ THE THUMBWHEEL SWITCH *********
810 W=PIN(15,14,12,13)
820 W=15-W                   :REM COMPLEMENT THE NUMBER
830 RETURN
840 REM
2000 REM **************** DISPLAY DATA (LCD) ********************
2010 REM
2020 G=0:H=0:                                  REM CLEAR DISPLAY ACCUMULATOR
2050 IF V<9999 I=0:J=128:GOTO 2080
2060 IF V<99999 I=128:J=0:V=V/10:GOTO 2080
2070 I=0:J=0:V=V/100
2080 X=V:                                      REM GET BACK
2090 K=X/1000:                                 REM STRIP NEXT DIGIT
2100 IF K=0 H=1:GOTO 2120:                     REM SUPPRESS LEADING ZERO
2110 V=X%1000:GOSUB 2260+(K*10):G=G+K:         REM NUMBER TO DISPLAY NEXT DIGIT
```

```
2120 X=V:                                     REM GET BACK
2130 K=X/100:                                 REM STRIP NEXT DIGIT
2140 IF H=1 IF K=0 H=2:GOTO 2160:             REM SUPPRESS LEADING ZERO
2150 V=X%100:GOSUB 2260+(K*10):G=G+(K*256):   REM NUMBER TO DISPLAY NEXT DIGIT
2160 X=V:                                     REM GET REST OF NUMBER BACK
2170 K=X/10:                                  REM STRIP NEXT DIGIT
2180 REM IF H=2 IF K=0 H=3:GOTO 1850:         REM SUPPRESS LEADING ZERO
2190 V=X%10:GOSUB 2260+(K*10):G=G+(K+J)*65536: REM NUMBER TO DISPLAY NEXT DIGIT
2200 K=V:GOSUB 2260+(K*10):H=K+I:             REM LSD
2210 SDO H,32:                                REM SEND 3 DIGIT TO DISPLAY
2220 SDO G,24:                                REM SEND Ø-2 DIGITS  TO DISPLAY
2230 RETURN
2240 REM ****************** TABLE ************************
2250 REM
2260 K=126:RETURN
2270 K=24: RETURN
2280 K=109:RETURN
2290 K=61: RETURN
2300 K=27: RETURN
2310 K=55: RETURN
2320 K=119:RETURN
2330 K=28: RETURN
2340 K=127:RETURN
2350 K=63: RETURN
2360 RETURN
3000 REM ********************* CLEAR MEMORY **********************
3010 IF PIN(1)=0 RETURN
3020 IF W<>0 GOTO 3010                :REM AREA MUST=0
3030 IF PIN(0)=1 GOTO 3010            :REM R/S MUST BE PUSHED
3040 X=0                              :REM CLEAR MEMORY
3050 PSET 10
3060 STORE X,#4,0
3070 IF X<2500 GOTO 3060
3080 PCLR 10
3090 GOTO 1
5000 REM*************** SUBROUTINE TO COLLECT DATA **********************
5010 REM @(1)=BASE OF THE CONE
5012 REM @(2)=BASE OF CONE - .5 * DEPTH INCREMENT
5014 REM @(3)=DEPTH INCREMENTS
5016 REM @(4)=LAST DEPTH+@(3)
5018 REM @(5)=LIMIT
5020 REM TRIGGER POINT =@(1)-CONE LENGTH
5055 Y=100:Z=300:T=500:C=0:PCLR 10
5057 @(4)=@(1)+(@(3)/2)                       :REM END OF FIRST DEPTH (MIDPOINT)
5060 REM
5070 IF CHAN(0)<25 RETURN                     :REM CONE IS NOT IN THE SOIL
5075 IF CHAN(1)>@(1) RETURN                   :REM CONE IS PAST FIRST DEPTH
5080 IF PIN(1)=0 RETURN                       :REM RUN/STOP SWITCH
5085 PRINT CHAN(1)
5090 IF CHAN(1)<@(2) GOTO 5080                :REM NOT TO FIRST SAMPLE LOCATION
5100 REM
5110 REM ~~~~~~~~~~~~~~~~~~~~~~ TIME TO TEST ~~~~~~~~~~~~~~~~~~~~~~~~~
5115 PSET 10                                  :REM TURN LIGHT ON
5120 REM
```

```
5130 REM Y=1ST STORAGE LOCATION POINTER FOR LOAD
5140 REM Z=1ST STORAGE LOCATION POINTER FOR DEPTH
5150 REM @(Y) & @(Z)=TEMPORARY DATA STORAGE
5160 N=N+1: =0                                :REM TEST NUMBER
5190 REM ~~~~~~~~~~~~~~~~~~~~~~~ TAKE A SAMPLE ~~~~~~~~~~~~~~~~~~~~~~~~
5200 REM
5210 @(Y)=0:@(Z)=0:@(T)=0                     :REM TEMPORARY DATA STORAGE
5220 S=0                                      :REM CLEAR # SAMPLES POINTER
5230 @(Y)=CHAN(0)+@(Y)                        :REM READ LOAD
5240 A=CHAN(1)                                :REM READ DEPTH
5250 @(Z)=A+@(Z)                              :REM STORE DEPTH
5255 S=S+1
5260 IF A>@(4) : PIN(1)=0 GOTO 5290           :REM LAST DEPTH
5280 GOTO 5230                                :REM GET ANOTHER SAMPLE
5290 @(T)=?                                   :REM READ TIME
5300 @(Y)=(@(Y)/S)-@(11)                      :REM AVERAGE LOADCELL READING
5305 IF @(Y)<0 @(Y)=0
5310 @(Z)=(@(Z)/S)-@(1)                       :REM AVERAGE DEPTH READING - OFFSET
5315 PRINT @(Z)
5317 @(10)=@(Y)
5320 Y=Y+1:Z=Z+1:T=T+1                        :REM INCREMENT THE POINTERS
5340 @(4)=@(4)+@(3)                           :REM LAST DEPTH + DEPTH INCREMENT
5350 REM ~~~~~~~~~~~~~~~~~~~~~~ CONDITIONS TO RUN ~~~~~~~~~~~~~~~~~~~~~
5360 REM
5370 IF PIN(1)=0 RETURN                       :REM STOP OR CONTINUE
5380 IF CHAN(1)>=@(5) GOTO 5400               :REM LIMIT
5385 C=C+1                                    :REM INCREMENT THE NUMBER OF SAMPLES
5387 V=(@(10)*10000)/@(8):GOSUB 2000
5390 GOTO 5190                                :REM NEXT SAMPLE
5400 V=(@(10)*10000)/@(8):GOSUB 2000
5440 PCLR 10:GOSUB 7000                       :REM STORE DATA
5450 RETURN                                   :REM FINISHED
6000 REM ******************** CALIBRATION ******************************
6010 REM
6020 IF PIN(1)=0 RETURN
6030 GOSUB 800                                :REM GET CHANNEL
6040 IF W=0 V=CHAN(0)*100
6050 IF W=1 V=CHAN(1)*100
6060 GOSUB 2000
6070 GOTO 6020
7000 REM ********************* STORE DATA ******************************
7002 REM
7010 REM 100=LOCATION IN @(0) ARRAY WHERE THE 1ST LOAD VALUE IS STORED
7020 REM 300=LOCATION IN @(0) ARRAY WHERE THE 1ST DEPTH VALUE IS STORED
7030 REM 500=LOCATION IN @(0) ARRAY WHERE THE 1ST TIME VALUE IS STORED
7040 REM #2=NUMBER OF 8 BIT BYTES IN WHICH TO STORE EACH VALUE
7050 REM D=IS THE AUTO INCREMENTING VARIABLE
7060 REM
7070 @(6)=D+6                                 :REM LOCATION TO MARK TEST
7072 Y=100:Z=300:T=500                        :REM LOCATION IN @(0) TO READ DATA
7074 IF C>@(12) C=@(12)                       :REM MAXIMUM # OF SAMPLES
7080 STORE D,#2,W                             :REM AREA
7090 STORE D,#2,N                             :REM TEST NUMBER
```

```
7100 STORE D,#2,M                          :REM CONE SIZE
7110 STORE D,#2,0                          :REM TEST MARKER
7120 FOR A=1 TO 3
7130 FOR B=0 TO C                          :REM 1 TO LAST (S) SAMPLE
7140 IF A=1 STORE D,#2,@(Z+B):GOTO 7170    :REM STORE DEPTH DATA POINT
7150 IF A=2 STORE D,#2,@(Y+B):GOTO 7170    :REM STORE LOAD DATA POINT
7160 IF A=3 STORE D,#2,@(T+B)              :REM STORE TIME OF SAMPLE
7170 NEXT B
7175 IF C=@(12) GOTO 7210
7180 FOR F=C+1 TO @(12)
7190 STORE D,#2,0                          :REM FILL THE REMAINDER WITH 0
7200 NEXT F
7210 NEXT A
7215 PRINT D
7220 RETURN
8000 REM *************************** MARK TEST ****************************
8010 REM
8020 IF PIN(0)=1 RETURN
8022 PSET 10
8024 STORE @(6),#2,1                       :REM MARK TEST
8026 SLEEP 100
8028 PCLR 10
8030 RETURN
9000 REM *************************** DUMP DATA ****************************
9010 REM
9020 FOR Y=1 TO 10:PRINT '':NEXT Y
9030 @(7)=D:D=0                            :REM SAVE DATA POINTER
9040 PRINT 'TURN CAPTURE ON IF YOU WANT TO SAVE THE DATA <CR>':INPUT''Y
9045 REM ~~~~~~~~~~~~~~~~~~~~~~ COLUMN SET-UP ~~~~~~~~~~~~~~~~~~~~~~~~~~~~
9050 FOR E=1 TO N                          :REM NUMBER OF TEST TO DUMP
9060 X=GET(D,#2)                           :REM RETRIEVE AREA
9065 IF E=1 PRINT '"     AREA= ',X,':';:GOTO 9080
9070 PRINT '     AREA= ',X,':';
9080 X=GET(D,#2)                           :REM RETRIEVE TEST #
9090 IF E=N PRINT '   TEST #= ',X,':"':GOTO 9140
9095 IF X<10 PRINT '   TEST #= ',X ,':';:GOTO 9140
9100 PRINT '   TEST #= ',X,':';
9140 D=E*608                               :REM NEXT TEST
9150 NEXT E
9160 D=4
9170 FOR E=1 TO N                          :REM NUMBER OF TEST TO DUMP
9180 X=GET(D,#2)                           :REM RETRIEVE AREA
9190 IF E=1 PRINT '"     CONE= ',X, :';:GOTO 9200
9195 PRINT '     CONE= ',X,':';
9200 X=GET(D,#2)                           :REM RETRIEVE MARK
9210 IF E=N PRINT '     MARK= ',X,':"':GOTO 9220
9215 PRINT '     MARK= ',X,':';
9220 D=E*608+4                               :REM NEXT TEST
9230 NEXT E
9250 FOR X=1 TO N
9260 IF X=1 PRINT'"   DEPTH    LOAD     TIME';:GOTO 9270
9265 IF X=N PRINT'     DEPTH    LOAD     TIME"':GOTO 9270
9267 PRINT           DEPTH    LOAD     TIME';
9270 NEXT X
```

```
9280 PRINT
9290 FOR X=0 TO @(12)                                  :REM NUMBER OF DATA POINTS
9300 D=8
9310 FOR Y=0 TO N-1                                    :REM NUMBER OF TEST
9320 A=(D*(Y+1))+(Y*600)
9330 C=A+(2*X)                                         :REM
9340 REM ~~~~~~~~~~~~~~~~~~~~~~~~~~ DEPTH ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
9345 B=GET(C,#2)                                       :REM RETRIEVE DEPTH
9350 B=B*10000/@(9)                                    :REM DATA*10000/SCALE FACTOR(23.93)
9360 Z=B%100                                           :REM Z=REMAINDER
9370 B=B/100                                           :REM B=INTEGER
9380 IF B=0 PRINT "     0.";:GOTO 9420
9390 IF B<10 PRINT "     ";:GOTO 9410
9400 IF B<100 PRINT "    ";
9410 PRINT B,".";
9420 IF Z<10 PRINT "0";
9430 PRINT Z;
9440 C=A+((2*X)+200)
9450 REM ~~~~~~~~~~~~~~~~~~~~~~~~~~ LOAD ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
9460 B=GET(C,#2)
9470 B=B*10000/@(8)                                    :REM DATA*1000/SCALE FACTOR(2.35)
9480 Z=B%100
9490 B=B/100
9500 IF B=0 PRINT "     0.";:GOTO 9550
9510 IF B<10 PRINT "     ";:GOTO 9540
9520 IF B<100 PRINT "    ";
9530 IF B>99 PRINT "   ";
9540 PRINT B,".";
9550 IF Z<10 PRINT "0";
9560 PRINT Z;
9565 C=A+((2*X)+400)
9570 REM ~~~~~~~~~~~~~~~~~~~~~~~~~~ TIME ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
9580 B=GET(C,#2)
9590 Z=B%100
9600 B=B/100
9610 IF B=0 PRINT "     0.";:GOTO 9660
9620 IF B<10 PRINT "     ";:GOTO 9650
9630 IF B<100 PRINT "    ";:GOTO 9650
9640 PRINT "   ";
9650 PRINT B,".";
9660 IF Z<10 PRINT "0";
9665 PRINT Z;
9670 NEXT Y
9680 PRINT
9685 SLEEP 100
9690 NEXT X
9700 D=@(7)                                            :REM RESTORE POINTER
9710 PRINT "TURN CAPTURE OFF <CR>"
9720 INPUT "CONTINUE (1) OR STOP (2) "Y
9730 IF Y=2 STOP
9740 IF Y<>1 GOTO 9720
9750 INPUT "SWITCH START/STOP SWITCH TO STOP TO CONTINUE <CR> "Y
9760 IF PIN(1)<>0 GOTO 9490
9770 RETURN
```

END
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